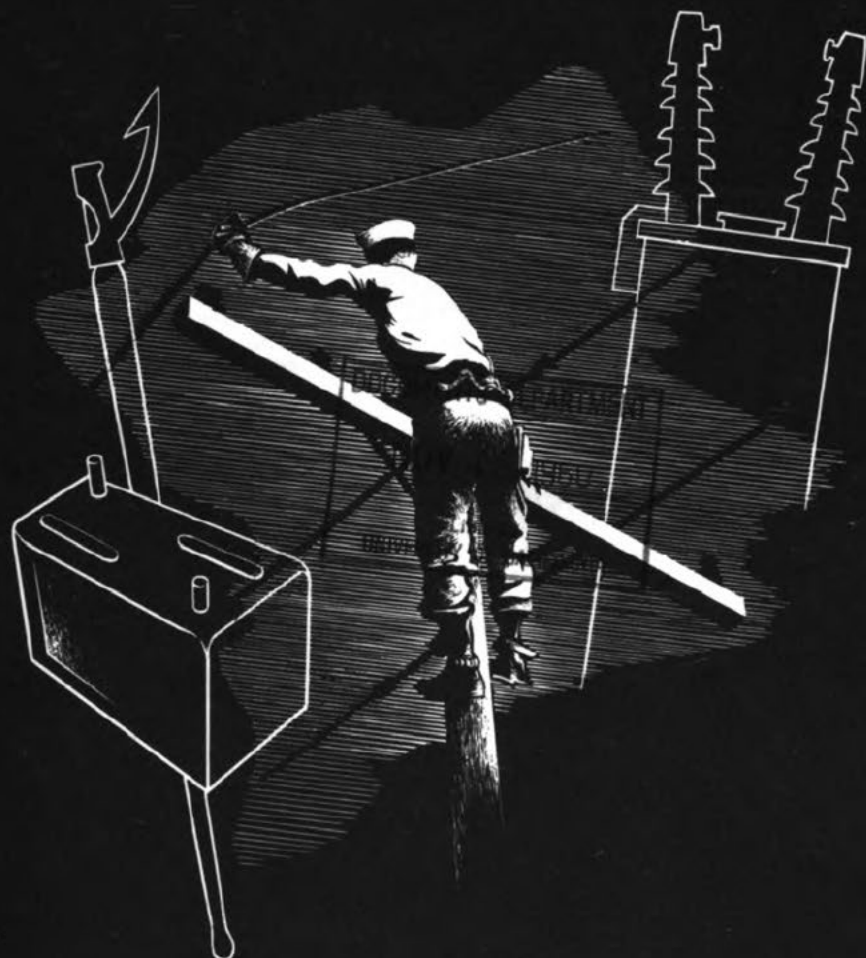

CONSTRUCTION ELECTRICIAN 3 & 2

BUREAU OF NAVAL PERSONNEL

NAVY TRAINING COURSE NAVPERS 10636-C

CONSTRUCTION ELECTRICIAN 3 & 2

Prepared by

BUREAU OF NAVAL PERSONNEL

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PREFACE

This training course has been prepared for men of the regular Navy and of the Naval Reserve who are studying for advancement to the rate of Construction Electrician 3 or Construction Electrician 2. The course is intended to supply information on the basic knowledges and skills required in the Construction Electrician rating. The principal factor in the selection of content for this course has been the *Manual of Qualifications for Advancement in Rating,* NavPers 18068 (Revised). Combined with the necessary practical experience and a study of the publications given in the reading list and other appropriate material, *Construction Electrician 3 & 2* will assist the student in preparing for advancement in rating.

The first chapter of this course is an introductory chapter. It briefly explains the structure of the Construction Electrician rating, discusses duties of the Construction Electrician, tells the method for advancement in rating, lists additional sources of information, and tells how the Construction Electrician fits into the Navy. The remainder of the course discusses technical material as it relates to the Construction Electrician rating. This material includes electrical diagrams and sketches, wiring, meters and controls, electrical generators and motors, electrical power and distribution systems, communication systems, and safety. The Study Guide on page vii indicates the chapters of this course that relate to the different service ratings. It is recommended, however, that the student study the entire course.

As one of the Navy Training Courses, *Construction Electrician 3 & 2* has been prepared by the U. S. Navy Training Publications Center, a field activity of the Bureau of Naval Personnel. Technical advice and assistance for this course have been given by the Bureau of Yards and Docks and the U. S. Naval Schools, Construction, Port Hueneme, California.

ACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A	E7 to E8	E8 to E9
SERVICE	4 mos. service—or completion of recruit training	6 mos. as E-2.	6 mos. as E-3.	12 mos. as E-4.	24 mos. as E-5	36 mos. as E-6.	48 mos. as E-7. 8 of 11 years total service must be enlisted. Must be permanent appointment.	24 mos. as E-8. 10 of 13 years total service must be enlisted.
SCHOOL	Recruit Training.		Class A for PR3, HM3, DT3, PT3.			Class B for AGCA, MUCA.		
PRACTICAL FACTORS	Locally prepared check-offs.	Records of Practical Factors, NavPers 760, must be completed for E-3 and all PO advancements.						
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.					
ENLISTEE PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.				Special evaluation required.	
EXAMINATIONS	Locally prepared tests.		Service-wide examinations required for all PO advancements.				Service-wide and selection board.	
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed.						
AUTHORIZATION	Commanding Officer U.S. Naval Examining Center						Bureau of Naval Personnel	
	TARS are advanced to fill vacancies and must be approved by CNARESTRA.							

*All advancements require commanding officer's recommendation.

INACTIVE DUTY ADVANCEMENT REQUIREMENTS

REQUIREMENTS*		E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7A
	FOR THESE DRILLS PER YEAR						
TOTAL TIME IN GRADE	24 OR 48	9 mos.	9 mos.	15 mos.	18 mos.	24 mos.	36 mos.
	12	9 mos.	15 mos.	21 mos.	24 mos.	36 mos.	42 mos.
	NON-DRILLING	12 mos.	24 mos.	24 mos.	36 mos.	48 mos.	48 mos.
DRILLS ATTENDED IN GRADE	48	27	27	45	54	72	108
	24	16	16	27	32	42	65
	12	8	13	19	21	32	38
TOTAL TRAINING DUTY IN GRADE	24 OR 48	14 days	14 days	14 days	14 days	28 days	42 days
	12	14 days	14 days	14 days	28 days	42 days	42 days
	NON-DRILLING	None	None	14 days	14 days	28 days	28 days
PERFORMANCE TESTS				Specific ratings must complete applicable performance tests before taking examination.			
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)		Record of Practical Factors, NavPers 1316 must be completed for all advancements.					
NAVY TRAINING COURSE (INCLUDING MILITARY REQUIREMENTS)		Completion of applicable course or courses must be entered in service record.					
EXAMINATION		Standard exams are used where available, otherwise locally prepared exams are used.					
AUTHORIZATION		District commandant or CNARESTRA					BuPers

*Recommendation by commanding officer required for all advancements.

#Active duty periods may be subsituted for drills and training duty.

THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

STUDY GUIDE

The table below indicates which chapters of this text apply to the rate to which you are seeking advancement. Select the column which applies to your rating, and check to see what chapters are indicated there. In most cases, the same chapters will apply to both Third Class and Second Class, under each specific rating.

Chapter	CEW	CEP	CET	CES
1	3, 2	3, 2	3, 2	3, 2
2	3, 2	3, 2	3, 2	3, 2
3	3, 2	3, 2	3, 2	3, 2
4	3, 2	3, 2	3, 2	3, 2
5	3, 2	3, 2	3, 2	3, 2
6		3, 2		3, 2
7		3, 2		3, 2
8			3, 2	
9			2	
10		3, 2		3, 2
11	3	3	3	3

READING LIST

NAVY TRAINING COURSES

Basic Electricity (ch. 1-16), NavPers 10086
Basic Hand Tool Skills, NavPers 10085
Blueprint Reading and Sketching (ch. 1-6, 9, 12), NavPers 10077-A

OTHER PUBLICATIONS

Advanced Base Electrical and Communications Systems (Part B, Section 1, and Part C), NavDocks TP-PL-15
Basic Electrical Engineering (ch. 1, Part B, and ch. 4), NavDocks TP-Te-5
Power Generation and Distribution (ch. 8, Parts B, C, D, and E), NavDocks TP-Pu-3
Electrical and Electronics Symbols, Military Standard 15-A

USAFI TEXTS

U. S. Armed Forces Institute (USAFI) courses for additional reading and study are available through your Information and Education Officer.* A partial list of those courses applicable to your rate follows:

Number	Title
C 290	Physics I
C 291	Physics II
B 781	Fundamentals of Electricity
A 784	Electric Wiring

*Members of the United States Armed Forces Reserve components, when on active duty, are eligible to enroll for USAFI courses, services, and materials if the orders calling them to active duty specify a period of 120 days or more, or if they have been on active duty for a period of 120 days or more, regardless of the time specified in the active duty orders.

CONTENTS

CONSTRUCTION ELECTRICIAN
3 & 2

Chapter 1

PREPARING FOR THE SERVICE RATINGS

The rating structure of the Navy, as currently established, consists of two types of ratings: the service ratings, and the general ratings. For Construction Electricians, the service rating is applicable to Petty Officers Third Class and Second Class; the general rating is applicable to Petty Officers First Class and Chief Petty Officers.

In general, we may define the difference between the two types of ratings in the following manner: men who qualify for the service ratings learn specific skills that enable them to perform all the duties required within a defined occupational area; men who qualify for the general ratings must have mastered all the occupational skills demanded of all the service ratings in their rating group, and must in addition have qualities and abilities that make them competent to instruct and train lower-rated men, and to act as supervisors and foremen. Another way to express this idea is to say that a service rating is a subdivision of a general rating.

Let nothing in the preceding paragraph lead you to suppose that the service ratings are less important than the general ratings. In any field, it takes time to master all the information and skills required in order to be expert. To use a familiar expression, everyone must learn to walk before he can run. The duties of the service ratings are fundamental to good overall performance in the Navy, and unless men are properly and adequately trained in these duties, the burden that would fall upon the men in the general ratings would be more than they could carry.

The duties of the service ratings are of immense importance in this rating group (Group VIII) in which you expect to make your rating. The assignments may be at overseas bases, established or in process of being built; they may be with military missions and legations in foreign countries; less often, they are at shore stations in the United States.

In our modern world, where technology is called upon to do our heavy labor, and to provide the services that make life, even at an advanced base, not too different from our normal environment, the Construction Electrician may truly feel that his contribution is immensely important. Upon him falls the obligation of installing, and maintaining in good operating condition, the systems that bring power for light, heat, cooking, laundry, and other facilities, and that provide the communications systems that keep contact alive between group and group, person and person.

There are four service ratings in the Construction Electrician rating group. These are: CEW (Wiring), CEP (Power), CET (Telephone), and CES (Shop). In this training manual, the duties of these various ratings have been kept separate, as far as possible, in order that each rating may START his training by reading only those chapters applicable to his particular service rating. What chapters apply to what service ratings is indicated in the Study Guide given in the front part of this book.

The phrase, "start his study," is used advisedly. Eventually, to advance to a general rating each service rating must have the knowledges and the skills required of all the other ratings in the Construction Electrician group.

The most practical approach to this broad field of technical information is to start in a modest way, and acquire a small fund of necessary information upon which to build. Therefore, the arrangement of the text in this training manual follows the qualifications established for each separate rating. A more logical arrangement, no doubt, would have resulted from organizing the material primarily on the basis of the overall subject matter. However, weighing the advantages and disadvantages of varying methods of organization, the arrangement according to service rating will probably prove the most desirable one.

TECHNICAL DUTIES

The technical duties of a CEW are to install and service interior wiring systems and secondary electric distribution systems. He must

also perform preventive maintenance, and make on-site repairs.

In order to accomplish these duties, he must be able not only to install the wiring and the circuits, but also such equipment as motors, generators, controllers, switchboards, distribution panels, and various types of electrical appliances.

The technical duties of the CEP are the installation, operation, and maintenance of electric generating systems, overhead and underground transmission lines.

The technical duties of the CET involve the installation and operation of overhead and underground wire communications systems. He must perform preventive maintenance on poles and lines, and be able to make repairs when weather conditions damage the line, or when operating conditions require the providing of additional circuits.

The technical duties of the CES are the overhaul and repair of generating equipment, motors, switchboards, controllers, and small electrical equipment.

These brief summations cover a great deal of work and learning. As the Construction Electrician studies his duties, he will realize that there are three major phases in which he must learn to operate: he must learn the tools and materials used in his calling; he must learn the proper work operations; and he must learn to demonstrate his worth by standing watches on electrical equipment.

Learning Tools and Equipment

In many technical occupations, it is possible to make some simple tool serve in place of the one specifically intended for a given piece of work. Such substitutions are not allowable in the Construction Electrician ratings. You will be provided with a kit of tools, and you must learn their uses, and use them in the intended manner.

You must keep the tools in good condition. Such items of protective clothing as you require must also be kept in first-class condition. In some occupational groups, failure to use the right tool might produce a poor piece of work, or one that may have to be completely redone. Failure on your part to use the right tool, or to have the right equipment on hand, could easily result in the severe injury of yourself or a fellow-workman.

The materials that you work with must be specifically chosen for the job in hand. A different sized wire from the one required can be the cause of fire or electric shock, as well as ruining the work you are doing. Carelessness in applying insulation, in making splices, in performing any one of a number of work operations, can mean a break in necessary services to your base or activity.

Learning Work Operations

When a man is fully trained in his technical profession, the right operation is almost second nature to him. While he is still in the learning stage, he makes many false moves, and many mistakes.

In your rating, it is especially important that you should be sure of what you are to do before you act. A false move can be followed by results far more serious than the embarassment of showing that you have not yet mastered your work processes. A mistake could be dangerous, or even fatal, to someone.

The specific work processes in which you must acquire proficiency before you can be promoted to a rate in your technical field are listed in the Qualifications for Advancement in Rating for Construction Electrician. These Qualifications (quals) are given in appendix III of this training course. They are discussed at greater length in the following section, Method of Advancement.

It is enough to mention here that these quals often imply a great deal more than they actually state. You will find such instructions as: Perform preventive maintenance on advance base generating equipment; Stand generator watches; Splice cable and make connections in electric distribution systems; Install signal circuits and public address systems. Before you can satisfactorily accomplish such instructions as these, you must have acquired a sound background in electrical theory, an ability to follow working drawings, a knowledge of the tools and materials required, and a facility in performing the necessary work processes.

METHOD OF ADVANCEMENT

Promotion from the service ratings is to the general ratings, with the added obligations imposed by (1) the necessity of knowing the practical and the knowledge factors of all the service

ratings in the Construction Electrician rating group; and (2) the responsibility of new supervisory and administrative duties.

From Chief Construction Electrician or Construction Electrician First Class, it is possible for you to become a Limited Duty Officer (LDO), Civil Engineer Corps. (Until 30 June 1960, it was possible to become a Warrant Officer, Civil Engineer Corps. After that date, warrant officers are to be gradually phased out of the Navy, and no more are to be appointed to warrant officer grade.)

Your first step along the path of advancement is to master the subject matter and the skills that pertain to the work of Construction Electrician Third Class. Your second step is to add to this acquired fund of knowledge all that is needed to enable you to qualify for Second Class.

Satisfying the Quals

Make a careful study of the quals in appendix III of this training course, because these are the points upon which you will be examined for promotion.

These qualifications are taken from the *Manual of Qualifications for Advancement in Rating,* NavPers 18068 (Rev.). The Construction Electrician is part of Group VIII of that manual. Because the manual is revised from time to time, you should make sure, before going for examination, that you have had access to the latest copy of these quals. The ones given in appendix III are the ones in effect at the time that this training course was given to the printer.

Read over these quals from time to time. As you recognize particular factors that you have already learned, you should make a point of demonstrating to a superior the fact that you now have proficiency in this factor.

A special form for recording proficiency in the practical factors of the various ratings has been made available for each of the service ratings in the Navy. This is NavPers Form 760: Record of Practical Factors.

Your supervising officer, or your division officer, will hold a copy of this form for you, and he will forward it with your enlisted service record if you are transferred to another billet. Whenever you show, by actual demonstration, that you are able to perform a given factor in your rating, the supervising (or division) officer will enter on Form 760 the date upon which you proved proficiency, and will initial that entry.

You will find it a good idea to maintain for your own use a duplicate copy of Form 760. Check it periodically, to see if there is some additional practical factor for which you are ready to be signed off.

Basic Navy Training Courses

A number of basic Navy Training Courses have been prepared for Navy men, in order to provide fundamental information in mathematical, electrical, and other technical fields. Much of this type of information is basic to a number of ratings, and it is more practical to assemble it in the basic courses than to repeat it in a wide number of training courses for specific ratings.

The basic courses that should be available to the Construction Electrician are:

Basic Electricity, NavPers 10086 (ch. 1-16, inclusive).

Blueprint Reading and Sketching, NavPers 10077-A (ch. 1-6, 9, 12).

In addition, there are certain other texts that are prescribed for all Navy personnel who are desirous of advancement in rating, and who are preparing for rating examinations.

The Bureau of Naval Personnel publishes periodically a booklet entitled *Training Publications for Advancement in Rating,* NavPers 10052. At the time that this training course went to the printer, the latest copy of NavPers 10052 was the revision lettered G, and issued in March 1959.

Make sure that you have an opportunity to see the latest revision, while you are studying for your rating training. The publications listed in the March 1959 issue, as prescribed study for the Construction Electrician 3 and 2, are also given in the reading list in the front part of this text. Changes in the prescribed list may occur, however, so check carefully upon this point.

BuDocks Technical Publications

The Bureau of Yards and Docks (BuDocks) has available a great number of technical publications dealing with various phases of construction work. In addition to the entries in the reading list, the following references are suggested as being a source of helpful information:

Basic Electrical Engineering, NavDocks TP-Te-5 (Sept 1955)

Chapter 1: Wire Communication and Signal Systems

Chapter 2: Lighting and Power Systems
Chapter 3: Lightning Protection...Radio Interference Suppression

Power Generation and Distribution, NavDocks TP-Pu-3 (Sept 1954)

Chapter 1: Electric Power Generation
Chapter 8: Electric Power Distribution

The technical books published by BuDocks are to a large extent intended for engineers in the field, and deal with certain aspects that will be outside the area of your responsibility. However, there is a great deal of background information that will be of great help to you.

Manufacturers' Operation Manuals

Never be careless in handling and conserving the operational manuals that accompany machines, meters, and other electrical components. The technical information given in these books is specific to the equipment with which you are working. Other texts may give you a broad and general knowledge of how a piece of apparatus operates, how it can be adjusted, how you can go about making repairs. But the operation manuals tie down all their instructions to the apparatus that is actually before you.

In the matter of maintenance and repair, these manuals generally provide you with a step-by-step procedure to be followed. Diagrams and photographs, with components identified, remove the element of guesswork. Where a knowledge of the general principles upon which a piece of equipment operates will often give you the clue as to how to overhaul or adjust it, the manufacturer's manual for the equipment removes all doubt.

To keep your electrical machines and devices in good working order, so as not to interrupt service to the various base activities, is important enough so that you should conserve any source of information that removes the element of trial and error.

Other Technical Handbooks

The mention of handbooks immediately brings to mind the *Lineman's Handbook,* by E. B. Kurtz. This excellent reference gives you the practical approach to the principles of electricity, and deals with such subjects as the erection of overhead lines; protective and control equipment; inspection, testing, and maintenance; and safety practices.

Throughout the book, emphasis is placed on the National Electric Code, which is the bible for men who work on any type of power distribution.

Lineman's Handbook is published by the McGraw-Hill Book Company, Inc., New York City. It has appeared in at least three editions; any of these is well worth having, but of course it is always advisable to have the latest edition, to derive the benefit from up-to-the-minute data, changes, and corrections.

The Construction Battalions at off-continent bases use equipment that is similar to that used by the Marine Corps and the Army. The Department of the Army has published a number of excellent manuals on electrical construction and electrical equipment. You are advised to consult the following technical publications, or at least as many of them as are readily available to you:

Electric Line Construction, TB-5-283-3 (June 1945)

Electric Motor and Generator Repair, TM5-764 (Dec 1955)

Electrical Facilities: General Engineering Data and Practices; Tools and Equipment, and Safety Practices; Repairs and Utilities. TM5-680 (May 1946)

Electrical Facilities: Generating Plants; Repairs and Utilities. TM5-680G (April 1947)

Telephone Cable Splicing, TM11-372 (May 1947)

LEADERSHIP

Three important factors in the career of any petty officer of the Navy are: knowledge, teamwork, and leadership. First you must learn the subject matter of your rating, and acquire proficiency in the manual skills that it requires. This mastery of the technical information for the CE service ratings will follow upon a study of the training course, and of the other texts to which you have been referred. The skills will come with practice in doing the work itself.

The Navy has made an investment in you, training you in the technical field that you have chosen. Into your training has gone the efforts and the concern of higher-rated men who have helped you by encouragement, by instruction, and by example.

When you make your rating, and have become a petty officer yourself, you are expected to share the knowledge and the skills you have

acquired. You have become a link in the chain of command between officers and lower-rated men, and one of your responsibilities will be to bear some of the burden of training others.

Many articles and books have been written on the general subject of leadership; but one thing is certain: if you cannot work WITH men, you will never gain their confidence to the point where you can LEAD them.

Have a sincere interest in passing on to other men the information that they need in order to perform their technical duties properly. It may sometimes be a temptation to lose patience with a slow learner, or to let your knowledge of job techniques make you overbearing with the men you are instructing. Think of leadership, however, as one of the duties that you are expected to master; learn it as you would a technical duty, and be as anxious to show that you have acquired proficiency in it as if it were a practical factor on Form 760.

A cooperative attitude in teaching other men is not the sole factor in leadership. You must be competent, and you must have self-confidence.

To be competent involves not only knowing how to do a specific job, but why it is to be done, and when and why other methods of doing it may not be followed. Where alternate methods ARE allowable, listen to the suggestions of the learners; sometimes you will find that they have practical and worthwhile ideas; and where you recognize that learning can be a two-way street, you gain the respect of the men that you are instructing.

On the other hand, where a work process is firmly established in order to avoid injury to personnel, equipment, or material, you should insist that this procedure be followed. You should take particular pains to see that the men perform it correctly—not once, but often enough so that there is no question of their mastery of the right method.

Self-confidence is a key to leadership; men are not favorably impressed by a wishy-washy attitude on matters that are part of your technical field. This self-confidence, however, must rest on a firm basis; it should stem from the fact that you thoroughly know your job.

Enthusiasm in teaching others is a part of leadership. If you like your job, know it well, and have a sense of duty to the Navy, you are bound to show some degree of enthusiasm in your work with lower-rated men.

This enthusiasm should not be limited to work operations. The influence that you exert is wider than that; so beyond the limits of your technical specialty, learn about the overall objectives of the Navy organization, and be ready to answer (or at least point to where answers can be obtained) when questions relating to Navy life in general are brought to you.

Read about the Navy. *This is Your Navy*, by Theodore Roscoe, is an excellent history, prepared by the U. S. Naval Institute. It will give you a complete picture of the development of our Navy, from Colonial days up to modern times.

PRIDE OF SERVICE

The more you learn about the Navy, the more you will appreciate your place in maintaining Navy traditions of accomplishment and service. The fact that you share this service with other men promotes a bond that may well become the basis of enduring friendships.

The Seabees are a very recent part of the development of our Navy, but already they have written some of the brightest pages in our military history. If you read of the accomplishments of this new branch of the services during World War II, of the way in which advanced bases were constructed in the Atlantic, the Pacific, the Mediterranean, and the Caribbean, you will feel yourself truly honored to be a part of an organization that found no job too tough to undertake, and to accomplish.

There are still bases to be manned, and huge construction projects to be accomplished. The Construction Forces are classed as fleet units of the Operating Forces, and their assignments are very likely to share the importance of the work done during war days, even though they may not share the dangers.

Although under a fleet commander for purposes of military command, the Seabees are under the technical control of the Bureau of Yards and Docks. The Chief of the Bureau is the Chief of Civil Engineers, and as such is also the top-ranking officer of the Civil Engineer Corps (CEC). Seabee activities are staffed almost entirely with CEC staff corps officers of the Regular Navy and of the Naval Reserve.

Your rating in one of these units represents an important job. Since your station will often be an off-continent one, you will not have all the

facilities of a shore station, and will many times have to demonstrate an unusual degree of self-reliance and resourcefulness.

Every service man, from the raw recruit to the highest ranking officer, can take just pride in knowing that he serves in a common effort to keep our country strong and free, and to preserve the liberties that have brought so many generations of freedom-loving people to our shores.

This sharing in a common endeavor can be a source of real pride to every service man. He can apply to himself the words spoken by President Eisenhower, concerning military service:

> There is something special about dedicating your lives to the United States of America that lives with you and, what is more important, in my opinion, with your children as long as they shall live.

CHAPTER 2

ELECTRICAL THEORY

Electricity may be produced in any one of a number of ways: by friction, pressure, heat, light, chemical action, and magnetism. Any of these natural forces, applied to a receptive material, can cause the loosely bound electrons that whirl about the nucleus of each individual atom in the material to become free electrons. Since these electrons are negatively charged, they will be attracted to neighboring atoms. The result of this will be to force the electrons of the neighboring atoms into motion, since the balance between positive nuclei and negatively charged electrons must be maintained. In this way, a constant movement is given to the electrons, and we say that we have an electric current flowing through the material.

The principles by which static electricity (electricity at rest) and dynamic electricity (electricity in motion) are produced is a subject that requires wide coverage. You can find these principles described in *Basic Electricity*, NavPers 10086. As a Construction Electrician, however, your work will be chiefly with electrical currents produced by the forces of magnetism. Occasionally, you may work with either secondary (wet) cells or primary (dry) cells, where chemical reactions produce an electric current; or you may need to understand the principle of the thermocouple, wherein current is produced by the application of heat to the junction of two dissimilar metals.

Before going any further into our subject, let us first make sure that you know the terminology of this technical field in which you are going to operate. Study the definitions given here, so that as you meet the terms later in the text of this training course, they will be familiar to you.

ELECTRICAL TERMINOLOGY

AMPERE is the practical unit for measuring the intensity of an electric current in a circuit; one ampere is the amount of current produced by a pressure of one volt in a circuit having a resistance of one ohm.

CAPACITANCE is the property of a circuit that opposes a change of voltage in the circuit. It may also be defined as the quality of a circuit that enables energy to be stored in an electrostatic field. The unit of measurement is the farad; capacity is one farad when one ampere PER SECOND, stored on the plates of the capacitor, causes a pressure of one volt across its terminals. In practical work, capacities are expressed in microfarads (millionths of a farad).

CAPACITIVE REACTANCE is the ratio of effective voltage across a capacitor to the effective current in an a-c circuit. It is opposition to current flow, in addition to the ohmic resistance of a circuit, due to capacity. The unit of measurement is the ohm.

CAPACITOR is a device for storing an electric charge. Some capacitors have a fixed capacitance (ratio of charge to voltage); others are so constructed as to have a variable capacitance.

CELL is a chemical device for obtaining a voltage, or electromotive force.

CONDUCTANCE is the ability of an electrical circuit to conduct current; the practical unit for measuring conductance is the mho (the reverse of ohm).

CONDUCTOR is a material or substance that is capable of serving as the path for the flow of electrons. Metals in general are good conductors; silver is the best, but for reasons of economy, copper is much more widely used.

CURRENT is the flow of electrons through a circuit; the practical unit by which intensity of flow or current is measured is the ampere.

EFFICIENCY of an electrical circuit or an electrical unit is the ratio of output power to input power.

ELECTRICAL FIELD is the space that lies between and around charged bodies, and in which their influence is felt.

ELECTRONS are negatively charged particles, whose movement through a conductor is called electric current.

ELECTROMOTIVE FORCE is the force that causes the movement of electrons in a conductor; it is usually referred to as emf, but may also be designated as electrical pressure, voltage, or difference of potential.

IMPEDANCE is the total opposition to flow of alternating current in a circuit that contains resistance (ohms) and reactance (ohms).

INDUCTANCE is the property of a circuit that opposes any change of current in the circuit; it may also be defined as the property whereby energy may be stored in a MAGNETIC field. The unit of measurement is the henry.

INDUCTIVE REACTANCE is the ratio between effective value of counter emf, and effective value of current; its unit of measurement is in ohms, when counter emf is in volts, and current in amperes.

INSULATORS are materials or substances that successfully oppose the flow of electrons; porcelain, glass, mica, quartz, bakelite, and rubber are examples of good insulator materials. Without the use of insulators, all current generated by whatever means would seek the quickest path to ground.

LINES OF FORCE designate the flux pattern existing in a magnetic field; commonly, it means the pattern of lines between the north and south poles of a magnet.

MAGNETIC FIELD is the area that lies around a magnet, and within which the magnetic force acts.

OHM—the practical unit of resistance in any resistive element (including a simple conductor) through which there is a current of one ampere, and across which there is a potential difference (or voltage drop) of one volt.

POTENTIAL DIFFERENCE is the difference in voltage (or electrical pressure) between the terminals of a conductor, or across a resistor element in the circuit. It is measured in volts. (Use of the term "potential energy" has been avoided in this training course; voltage or electrical pressure have been used as its stead.)

POWER is the rate of doing work; it is measured in watts.

REACTANCE—see capacitive reactance, and inductive reactance.

RESISTANCE is the quality of an electrical circuit that opposes the flow of current through the circuit; it is measured in ohms.

VOLT is the practical unit of measure of an electromotive force, or of the difference in potential.

VOLTAGE—see electromotive force, and potential difference.

WATT is the practical unit for expressing the power of a circuit; power in watts, multiplied by the time factor, represents the energy made available. Energy is usually expressed as kilowatt-hours, with one kilowatt equalling one thousand watts. To express WATTS as equivalent horsepower, divide by 746 (1 hp = 746 watts).

In addition to understanding the meaning of these basic definitions, you must have some knowledge of the character of electrical equipment. For example, you must know what motors do, how they differ from generators, and how they are related to dynamos and to alternators.

Ordinarily, a motor is a device for transforming electrical energy into mechanical energy. The electrical energy must be fed into the motor, which changes it to useful work.

A generator is a device for transforming mechanical energy into electrical energy.

A transformer is a device for stepping up or down the voltage of a generator. An auto-transformer can be used with an a-c motor (with the motor leads connected to secondary taps on the transformer) to start the motor at a reduced voltage.

An alternator is a generator producing alternating current.

A dynamo is a mechanism that may be used either as a d-c generator or as a d-c motor. In the first case, the dynamo is driven mechanically, and furnishes electric power; in the second case, electric energy is fed to the dynamo, which then furnishes mechanical power.

PROPERTIES OF ELECTRICAL CIRCUITS

In a good conductor (that is, one containing free electrons), the outer electrons of the atom can be easily removed. This starts the motion of electrons that we describe as "flow of electric current." Whatever the source that produces an electric current, it is essentially nothing more than a device for starting motion among the free electrons. The law by which like charges repel each other explains why this motion of electrons, once started, travels the length of the conductor.

Since electrons are negatively charged, direction of OVERALL motion of the electrons is from the negative terminal of the source (cell, generator, and so on) through the external circuit (the conductor) back to the positive terminal.

In the early days of electrical experiment, before the nature of the atom was fully understood, it was naturally assumed that the flow of electric current was from the positive to the negative source. Many textbooks and manuals continue to use the conventional, although inaccurate, presentation of current as a movement of positive charges. Others present current flow as the movement of negative charges, which it actually is.

Basic Circuit

The electric circuit consists primarily of a source of potential difference; a conductor; and a device (switch) for cutting the source in or out, since current will not flow except in a closed circuit. For practical use, there will be a load in the line, or circuit; this load may be an electric light, a household appliance, a motor, a capacitor (device for temporarily storing electricity), or a dynamo. The service required of electrical circuits can be anything from the ringing of a bell when a pushbutton is depressed to the furnishing of heat, light, and mechanical energy to meet the needs of a community.

Whether complex or of the simplest possible type, all circuits involve the practical electrical units known as volts, amperes, ohms, and watts.

Voltage is the difference in potential across the negative and positive terminals of the energizing source. When the switch is thrown to close a circuit, this difference in potential, in its tendency to equalize itself, starts the flow of electrons. The amount of the electric current thus generated is directly proportional to the voltage applied, and inversely proportional to the resistance of the circuit.

There is always some resistance to the flow of current in the conductor itself, depending chiefly upon the length and cross sectional area of the conductor, and the material of which it is made. There is usually some resistance in the source, also; this will be mentioned again in connection with series circuits.

Probably the greatest resistance, in any circuit, is that of the load, or loads, cut into the line. Except in a circuit where the length and cross-sectional area of the conductors is such that they represent a noticeable resistance to the current drawn through them, the term resistance is understood to mean that of the load cut into the circuit, or of the load plus the resistance in the source itself.

Ohm's Law

In the preceding three paragraphs, you no doubt recognized the essential factors expressed in Ohm's law, which is usually stated as follows:

THE AMOUNT OF THE CURRENT IN AMPERES IN AN ELECTRICAL CIRCUIT IS EQUAL TO THE DIFFERENCE IN POTENTIAL IN VOLTS ACROSS THE CIRCUIT DIVIDED BY THE RESISTANCE IN OHMS OF THE CIRCUIT.

It is usual to express this law as an equation,

$$I = \frac{E}{R}$$

where I represents current, E voltage, and R resistance.

From this equation, it is possible to deduce a number of facts in relation to a flow of direct current through a simple circuit. For example:

1. If any two quantities (E and I, E and R, or I and R) are known, it is a simple matter to find the value of the other quantity.
2. If the voltage is held constant, the current varies inversely with the resistance.
3. If the resistance in the circuit is held constant, the current varies directly with the applied voltage.
4. If the current is maintained at a constant amperage, the voltage across the circuit load will depend upon the resistance of the load, and will vary directly with the resistance.

The purpose of installing an electrical circuit is to arrange a device for doing useful work. The current is induced in order that electrical energy may be converted into mechanical energy. The unit of power for performing work is the watt, and this is equal to the product of the voltage and the current in the circuit. Expressed in the form of an equation, this relationship is

$$P = EI$$

From the equation showing the interrelationship of current, voltage, and resistance, we see that $I = \frac{E}{R}$. Substituting $\frac{E}{R}$ for I, in the power equation just given, we obtain

$$P = E\,(E/R) = \frac{E^2}{R}$$

This tells us that the power delivered to a circuit varies directly as the square of the applied voltage, and inversely as the resistance in the circuit.

Again inspecting the equation form of Ohm's law, we see that $E = I R$; that is, voltage is equal to the product of current and resistance. Substituting IR for E in the power equation, we obtain

$$P = (IR)\ I$$
$$= I^2\ R$$

This tells us that power in watts in a circuit varies directly as the product of the resistance in ohms and the square of the current in amperes. If resistance is held constant, the power delivered varies directly as the square of the voltage applied, and directly as the square of the current in the circuit.

Series and Parallel Circuits

Few circuits will be simple direct-current circuits serving only one resistive element. In a good-sized electrical system, there will be multiple sources, many simple circuits combined to form a network of conductors, a variety of resistive elements, and various devices for energizing or breaking circuits, and for controlling and regulating voltage and current.

Resistive elements may occur in SERIES in a circuit; that is, there may be only one path along which the flow of electrons from a single source may travel. If there are two or more paths along which current travels from a common voltage source, the circuit is a PARALLEL circuit.

In a series circuit, adding resistors will increase the opposition to electron flow. In a parallel circuit, the more resistors (in parallel) the more paths there are for the flow of electrons, and the less opposition there is to this flow.

Resistors may be connected in combinations of series and parallel arrangements. For example, bridge circuits contain series-parallel groups connected by a common bridge. Ordinarily, the analyses of bridge circuits is a job of the Construction Electrician First Class. As you develop technical knowledge, you will learn how to recognize and separate these combination circuits, and how to solve circuit problems by using the basic laws of electricity.

Kirchhoff's Laws

We have already defined Ohm's law of basic relationships between voltage, current, and resistance, and have seen how this law can be used to solve for unknown values of either current, resistance, or voltage in a simple circuit. Solving for unknown values in series and parallel circuits is made easier by the use of Kirchhoff's laws, which are developed from Ohm's law. These two derived laws are known, specifically, as Kirchhoff's LAW OF VOLTAGES and Kirchhoff's CURRENT LAW.

When we express Ohm's law as $E = IR$, we can see that theoretically, at the close of any circuit, the E factor has been completely "used up" in maintaining current I against the opposition offered by resistance R. Actually, there must be some terminal voltage in any circuit, to ensure satisfactory service. But with $E = IR$ in mind, it may be easier to understand Kirchhoff's law of voltages, which states that the algebraic sum of the voltages around a circuit is equal to zero. In other words, the total voltage, minus the sum of voltage drop across the loads, is zero.

For example, you start with a specified voltage at the source; we may call this E_t (understanding the small t to represent total). There are, let us say, four resistor elements in the circuit. The difference between the voltage just behind a resistor, and the voltage just beyond, represents the voltage drop across the resistor. Designating the individual voltage drops across each of the four resistor elements as E_1, E_2, E_3, and E_4, we can see that

$$E_t - E_1 - E_2 - E_3 - E_4 = 0$$

Conversely, we can obtain the voltage for the circuit by adding the voltage drops across the various resistors; that is,

$$E_t = E_1 + E_2 + E_3 + E_4$$

Figure 2-1 illustrates a series circuit into which four resistors have been introduced. At each resistor, as we know from Ohm's law, $E = IR$, and for the whole circuit, $E = IR$. If we substitute the IR values for the E's in the equation just above, we have

$$IR_t = IR_1 + IR_2 + IR_3 + IR_4$$

However, in a series circuit such as this, there is only one path along which the current flows, and therefore the total current is the same in all parts of the circuit. We can divide the equation which we have just derived by I, since it has an identical value in each term. As a result, we find that

$$R_t = R_1 + R_2 + R_3 + R_4$$

or, the total resistance in a series circuit is the sum of the individual resistances. This may

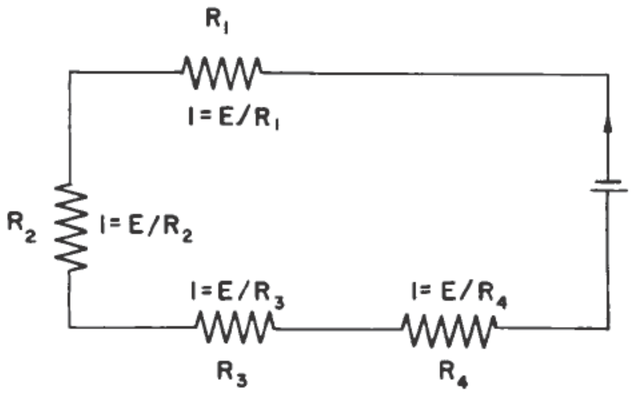


Figure 2-1.—Series circuit.

SEEM an obvious conclusion for any type of circuit; but actually this is not true of parallel circuits.

As with Ohm's law, the formulas that can be derived from the law of voltages are a ready means of solving series circuit problems.

In a parallel circuit, the loads are each connected directly with the voltage source, and it is current that varies. Figure 2-2 illustrates such a circuit. Voltage across each resistor is 30 volts, and the resistance of the individual resistor elements is 5, 10, and 30 ohms, respectively.

Current through each resistor varies (in accordance with the basic formula, $I = E/R$) according to the resistance of the element. Perhaps your first reaction, in seeking to determine the total current in the circuit, would be to find the average resistance, and divide that figure into the known voltage value. This would give you 15 ohms as an average, and 2 amps for total current; and it would be a completely wrong answer.

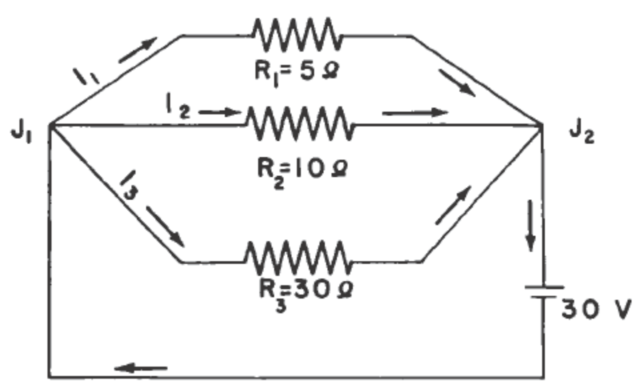


Figure 2-2.—Parallel circuit.

The total current is the sum of the individual currents through the paths made available; it is therefore the sum of the currents through each resistor element.

I_1	(E/R for R_1)	$= 30\text{ v}/\ 5\ \Omega$	or 6 amp
I_2		$= 30\text{ v}/10\ \Omega$	or 3 amp
I_3		$= 30\text{ v}/30\ \Omega$	or 1 amp
I_t	(total current)		$= 10$ amp

Kirchhoff's current law states that at any junction in a circuit the algebraic sum of the currents is zero; that is, as many electrons leave the junction as enter it. If we consider that a current of 10 amp enters at J_1, where it "splits" to follow the three paths, we can see how this law is borne out by the facts:

$$I_t = I_1 + I_2 + I_3$$

but, algebraically,

$$I_t - I_1 - I_2 - I_3 = 0$$

Again at junction J_2 the three individual currents unite to form a total current of 10 amps; and again, by subtracting the sum of the currents through the resistors from the total current, we get zero.

Having found the total current in the circuit by means of the relationship between voltage and individual resistors, let us see what we know about the total resistance of the circuit:

$$I\ (10) = \frac{E\ (30)}{R}$$

Therefore, R must be 3 ohms.

This should immediately convince you of the advantage of parallel circuits, since it demonstrates that the total resistance in such a circuit is less than the resistance of the smallest resistor element in any of the branches.

Each I in the formula for the law of currents can be expressed as E/R; therefore,

$$\frac{E_t}{R_t} = \frac{E_t}{R_1} + \frac{E_t}{R_2} + \frac{E_t}{R_3}$$

Dividing through by the common factor, E_t, we obtain

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

This is the correct procedure for determining resistance in a parallel circuit. The quantities, $\frac{1}{R_1}$, $\frac{1}{R_2}$, and so on, are the reciprocals of the specific resistances, and represent CONDUCTANCE, or the ability of the circuit to conduct current.

The chart in figure 2-3 will help you to determine the equations that you should use in solving for the quantities volt, ampere, ohm, and watt. Substitute the known quantities, and solve for the unknown.

You will find a much fuller explanation of series and parallel circuits, and examples of how to solve various circuit problems, in chapter 4 of NavPers 10086.

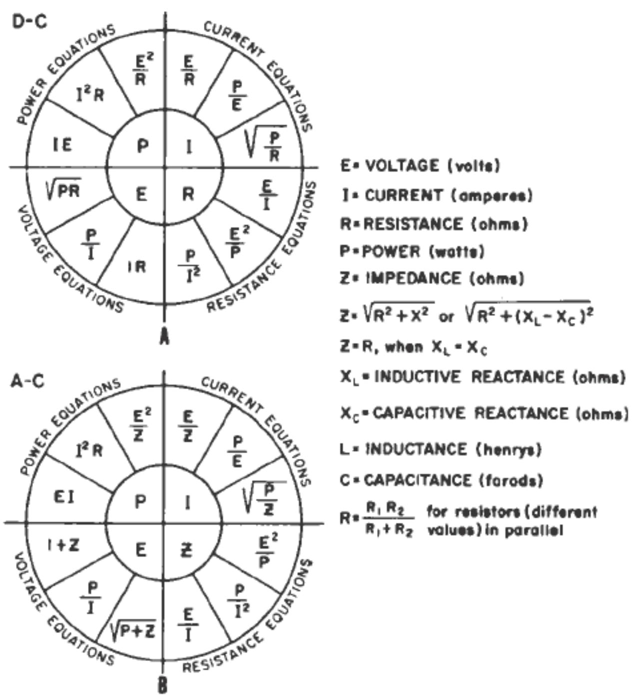


Figure 2-3.—Relations between E, I, R, and P in basic d-c and a-c circuits.

ELECTRICAL PRINCIPLES AS APPLIED TO MOTORS

In any branch of electrical work, it is necessary to understand the operating principles and characteristics of motors, and types of construction. The basic principles of generators, and their operation, maintenance, and repair, are chiefly the concern of the CEP and the CES service ratings, and are dealt with in chapters 6, 7, and 10 of this training course. All service ratings, however, are responsible for knowing something about a-c and d-c motors.

Motors operate on the principle of two magnetic fields reacting upon each other. Pole pieces, frame, and field coils form one field; and as current is sent through the armature windings, a magnetic field is set up about the armature.

The important parts of a motor, then, are the poles and the armature. The poles are ordinarily the static part, and the armature the rotating part.

The poles are formed by placing magnetized bars so that the north pole of one opposes the south pole of the other. The air gap between these poles is the magnetic field.

Just as a conductor must be insulated to prevent its electrical charge from being grounded, so the magnetic field must be shielded from the earth's magnetic field, or from the field of nearby generators or motors. This shielding is usually done by surrounding the field with a shell of soft iron.

The armature carries the coils which cut the lines of force in the field.

Direct Current Motors

In a direct current motor, the necessary MAGNETIC CIRCUIT is formed by the pole pieces, supported by the yoke, and by the armature core, mounted on a shaft that passes through the air gap between the pole pieces, and that is secured at either end to the yoke. Magnetic lines of force pass through the magnetic circuit, but are not produced by the circuit. The magnetic field is produced by the field coils, which are part of the ELECTRICAL CIRCUIT.

A single wire cutting the lines of force in a magnetic field would usually not provide a sufficient means for doing work. The strength of the current depends upon the number of lines cut; it is therefore necessary to add a number of wires (conductors) until the desired strength is obtained.

Suppose the conductors were allowed to swing like a pendulum, or to pass rapidly back and forth across the magnetic field. The motion would be less efficient than that produced by a rotating movement; for instance, there would not be the momentum to swing the coil back when it had reached its limit of travel.

With the rotating device shown in figure 2-4, this cutting motion is speeded up so that the coil is rapidly cutting across the lines of force. There is still a slight lag when the coil is at right angles to the lines of force; it is then passing through the neutral plane, and the upward and downward forces cannot produce a turning

motion (torque) until the momentum of the coil carries it slightly beyond the vertical position.

To eliminate these points of zero torque, which in the actual operation of a motor would result in jerky rotation, it is customary to use two coils, placed at right angles as illustrated in figure 2-5. The use of a second coil has the additional advantage of making the motor stronger.

The CONSTRUCTION of the d-c motor is designed to make use of the reaction between two magnetic fields. The first field is produced by electromagnets mounted in an iron frame, called a yoke, and wound so as to ensure opposite polarity. The yoke, pole pieces, windings, and field, make up the primary circuit.

The construction of the field coils is a simple matter. They consist of a number of turns of wire, wound on a form to the size required, and wrapped in cotton tape or varnished cambric.

Fitted into the area between the pole pieces is an armature, consisting of a grooved drum mounted on a shaft. This shaft also carries the commutator rings. The conductors are laid in the grooves along the armature, and locked into the slotted ends. The coil on the armature produces the secondary circuit.

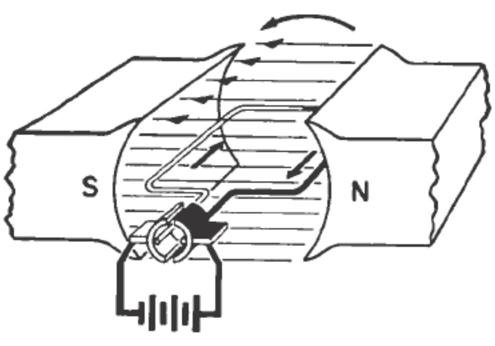


Figure 2-4.—Single-turn coil mounted in a magnetic field.

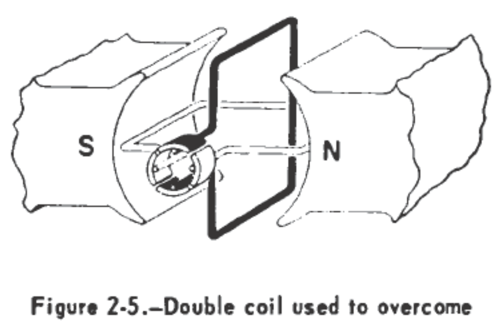


Figure 2-5.—Double coil used to overcome zero torque.

The commutator ring is in segments, each of which is in sliding contact with a block of carbon, called a BRUSH. One brush is known as the positive brush, the other as the negative brush. At the instant of negative torque, or dead center, the segments of the commutator switch brushes, and the current reverses. This reverses the coil current and maintains the torque in the proper direction; but the current fed to the brushes from the external circuit is always in the same direction.

As mentioned before, the pole pieces, windings, and field form the primary circuit, and the conductors wound on the armature form the secondary circuit. As current flows through these conductors, they set up fields of their own, and it is the reaction of these conductor fields with the fields of the pole pieces that produces the torque, or rotating motion.

With the rotation of the armature, its conductors cut through the field flux, and a voltage is induced in the conductors. It is opposite to the voltage at the brushes. This induced voltage is called the counter emf, and is always counter to, and less than, the applied voltage. So far from reducing the efficiency of a motor, the counter emf is of great advantage in the safe operation of the unit.

Suppose the applied voltage to be 110 v, and the resistance of the armature is 1 ohm. When the circuit is closed, you have a current of 110 amp flowing through the small windings of the armature. But, after the instant of starting, the armature begins to produce its counter emf, opposite in action to the 110 v, and thereby reducing the applied voltage to a lower effective voltage.

As the speed of the motor increases, the conductors on the armature cut more lines of force per any given unit of time, and the counter emf increases. Again, as it increases, it lowers the value of the applied emf, and the current correspondingly decreases. By the time that the motor has reached full speed, the current will have decreased to a safe value.

TYPES of d-c motors are: series, shunt, and compound. Series motors are particularly good where heavy loads are coupled to the motor; shunt and compound motors are of advantage where speed of load must remain practically constant.

A series motor, as its name suggests, has field windings and armature connected in series. As load is added to a series motor, more current flows through the armature. As this

current flows through the series field, a greater counter emf will be produced, and the motor speed will decrease.

The characteristic of this type of motor, therefore, is that when torque is high, speed is low; conversely, when torque is low, speed is high. If the motor were ever started without a load, the armature would speed up to such an extent that the armature windings might be torn loose from the slots.

The series motor is never belt-connected to a load, for fear that the belt would slip and the motor would overspeed. Connections, therefore, should be direct to the load, or through gears. The best method of controlling speed is to insert a resistance in series with the armature.

The shunt motor has field windings and armature connected in parallel. If supply voltage remains constant, current through the field coils remains constant. An increase in armature current will increase the torque, but will not affect the field current.

When there is no load on the motor, a fairly small armature current is all that is required to produce enough torque to overcome bearing friction and windage. When a load is applied, the motor tends to slow down slightly, and the decrease in speed causes a corresponding decrease in the counter emf. As counter emf decreases, a larger current flows through the armature, and the torque increases. When the torque on the motor equals the resisting torque of the load, the speed of the motor becomes constant until change of load occurs. Speed at full load is usually about 10 percent less than speed at no load.

If you were to decrease the load on a shunt motor, you would find the motor speeding up slightly, toward the no-load speed. This increase in speed will cause a corresponding increase in counter emf (since the higher the speed of rotation, the greater number of lines of force cut in a given time); and the increased counter emf effects a corresponding decrease in armature current, and consequently in torque.

With the series motor, speed is controlled by inserting a resistance in series with the armature, but for a shunt motor, the resistor element must be in series with the field. A rheostat will permit increasing or decreasing resistance, as desired. Decreased resistance means that more current flows in the field coils, and the motor slows down. Increasing resistance results in a decrease in field current, and the motor speeds up.

Compound motors are just what their name suggests—that is, they have both a shunt and a series field. When the series winding is connected so that its field AIDS the field of the shunt winding, the motor is called a CUMULATIVE compound motor. If the series winding is connected so that the field OPPOSES the field of the shunt winding, the motor is called a DIFFERENTIAL compound motor.

Speed of a cumulative compound motor decreases more rapidly than that of a shunt motor, once the load is applied. Shorting out the cumulative series winding once the motor comes up to regular speed, gives good speed regulation.

Speed of a differential compound motor with heavy overload may become unstable; if overload current is very heavy, there may be a reversal of rotation. When this happens, the motor runs as a series motor, with the risk of damage to the equipment.

Motors (and generators also) have three DIRECTIONS in which they operate. First, there is the direction of the conductor current; second, there is the direction of the field flux; third, there is the direction of actual motion.

If you extend your right hand so that thumb and middle finger are perpendicular to the index finger, you have an example of how these three directions are related to each other. With your middle finger pointing in the direction of current flow in the conductor, and your index finger in the direction of the magnetic lines, your thumb points in the direction of the force acting on the conductor. This latter, of course, is the direction in which the conductor actually moves.

This hand rule is known as Fleming's Right-Hand Rule for a Motor. A similar rule can be used for determining directions in a generator, but you must use your LEFT hand instead of your right hand.

The armature WINDINGS, with the commutator and brushes, complete the electrical circuit. Since the armature windings are part of the circuit, they must be insulated from the armature core; for this reason, the slots in the armature surface are lined with thin insulation paper. The windings are positioned so that while one side of a coil is passing the north pole, the other side is passing the south pole. Inserting the windings in the slots prevents their being thrown off when the armature core is rotating at high speeds.

The armature windings must be connected with the external circuit; no direct connection is possible, because the windings rotate with

the core, but the commutator and brushes provide a sliding contact. The brushes, which are stationary, are connected to the external circuit. They transfer current from the commutator, fastened to and rotating with the armature windings, as contact is made between commutator and brushes.

It might be mentioned here that the wiring diagram for a d-c generator is similar to that for a d-c motor. The basic difference is that in the generator the coils turn and produce electric current, and that this current is then transferred to the external circuit.

Figures 2-6 and 2-7 show the wiring diagrams for a series motor and a shunt motor, respectively.

In a series motor, the field coils are made up of a few turns of large wire. That means that coil resistance is low, and there is a minimum reduction of the amount of current flowing through the armature windings. From a study of figure 2-6, you can see that the field coils and

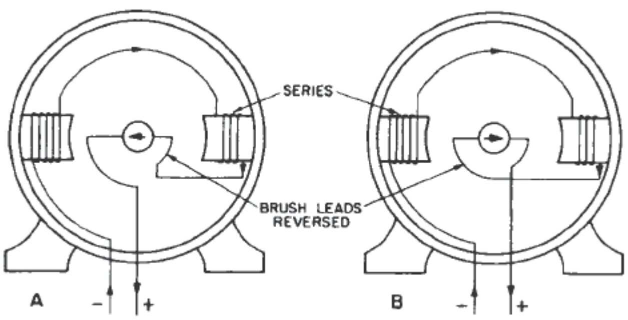


Figure 2-6.—Wiring diagram for a series motor.

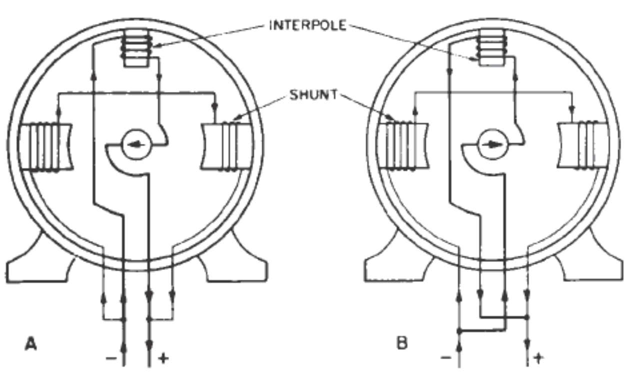


Figure 2-7.—Wiring diagram for a shunt motor. Note that in B, the direction of current flow through the armature is reversed.

the armature windings form a series circuit, since the same current flows through them. You can also see how reversing the leads reverses the current flow through the armature, and changes the direction of rotation of the motor.

In the shunt type of motor (fig. 2-7), the field coils consist of a great many turns of small-diameter wire. The added number of turns means that there is high resistance, and a correspondingly low current flow. Note that the field windings have here been placed in parallel with the armature windings, by shunting a part of the current through windings on an interpole, and then through the armature. To reverse this type of motor, the armature and interpole leads are reversed as a unit; the polarity of the field coils remains unchanged.

By use of the shunt, the low current through the field windings is held almost constant, and only the current through the armature varies with load. This gives the shunt motor the advantage of holding a fairly constant speed over a wide range of load changes.

Alternating Current Motors

Most of your work with motors, at shore stations especially, will be with a-c motors. There are certain advantages with d-c motors, and you must know the principles upon which they operate; but a-c power is more widely used, and a-c motors are less expensive and, on the whole, more reliable.

For example, sparking at the brushes of a d-c motor can be very dangerous if there is explosive gas or dust in the surrounding air. On many a-c motors, brushes and commutators are not used. In addition, a-c motors require a minimum of maintenance; they are suited to constant-speed applications; and they are designed to operate at different number of phases, and voltages.

There are certain basic differences between the way in which d-c motors are built, and the design of an equipment which is run on alternating current. Any coil that rotates in a magnetic field will have an a-c voltage induced in it, so it is not current that makes the essential difference between the two kinds of motors. Rather, it is the way in which the current is taken from the external circuit.

In the case of d-c motors, we saw that when the coil passed dead center, and the current

reversed, the commutator segments also reversed brush connections. In an a-c motor, the coil terminals are sometimes attached to slip rings of good conductor material; brushes riding on these slip rings pick up current from the external circuit, just as with the d-c motors.

However, there is a low limit on the voltage. With high voltages, there would be dangerous arcing between the slip rings and the brushes, and even between ring and ring, brush and brush, and brush and frame.

The design used in most a-c synchronous motors (but not polyphase induction motors), is that of a ROTATING MAGNETIC FIELD, with stationary armature. The rotor now is the field, and the stator is the armature, whereas in the d-c motor, the stator is the field, and the rotor is the armature.

With enough turns on both rotor and stator, it is possible to build up a high voltage, since the multiturn stator is connected in series, and the voltages are added to each other. The provision for ensuring that voltage always goes through the load, even though current reverses direction periodically, is taken care of by the manner in which the windings are connected (see fig. 2-8).

WINDINGS on A-C MOTORS are simpler, on the whole, than those on d-c motors. This is because there are no commutator segments on a-c machines; fewer turns, therefore, are needed, and no commutator connections are required.

On most a-c motors, the armature windings are placed in the stator, since this arrangement protects them from the centrifugal force of the rotor. This protection is an important feature, because voltages and currents provided for the armature are higher than those in the field coils.

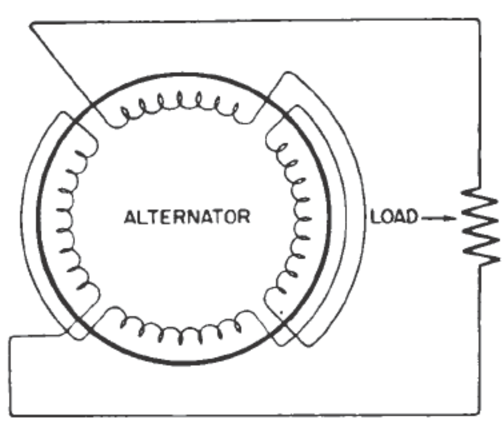


Figure 2-8.—Schematic of stator and load.

Another difference is that most a-c motors have windings of the open circuit type, as opposed to the closed circuits of d-c motors.

Single-phase windings are those in which the coils are connected in series, with one set of coils terminating in two free ends. Polyphase windings consist of two or more single-phase windings symmetrically spaced on the armature.

The most common type of polyphase windings are the three-phase windings. These may be either Y-connected or delta-connected, as indicated in figures 2-9 and 2-10, and the circuits may be either in series or in parallel.

According to whether windings in a three-phase motor are Y-connected or delta-connected, voltage and current values in the individual phases will vary from voltage and current values across the line terminals. For the Y-connected stator or armature, line voltage is 1.73 times phase voltage, but line current and phase current are the same value. For a delta-connected armature, line voltage is equal to phase voltage, but line current is 1.73 times phase current.

At this point, you probably will need to refresh your memory on what is meant by PHASING. When there is more than one winding on a stator, the flux field of the rotor does not cut each winding at the same time. As a result, the induced voltages in the two windings have a different timing. This difference in timing is termed phasing.

A single-phase induction motor must be manually started before it sets up a rotating magnetic field. When a single-phase motor can be made self-starting (that is, when it can be provided with a starting torque other than manually applied), it is known as a split-phase, capacitor, repulsion, or series-Universal, according to the type of starting method.

Single-phase motors are used in interior communication systems, and are also used for driving small equipment, such as portable tools, fans, and refrigerators.

The TYPES of a-c motors that are operated on polyphase circuits are more commonly used. The degree to which voltages in polyphase circuits are out of timing can be accurately measured, if instead of using the time unit of one second, you use the electrical degree as a unit.

In a 2-pole machine, a single complete revolution (or rotation) of the rotor corresponds to 360 electrical degrees, and to 360 angular degrees; and since the time unit also relates to

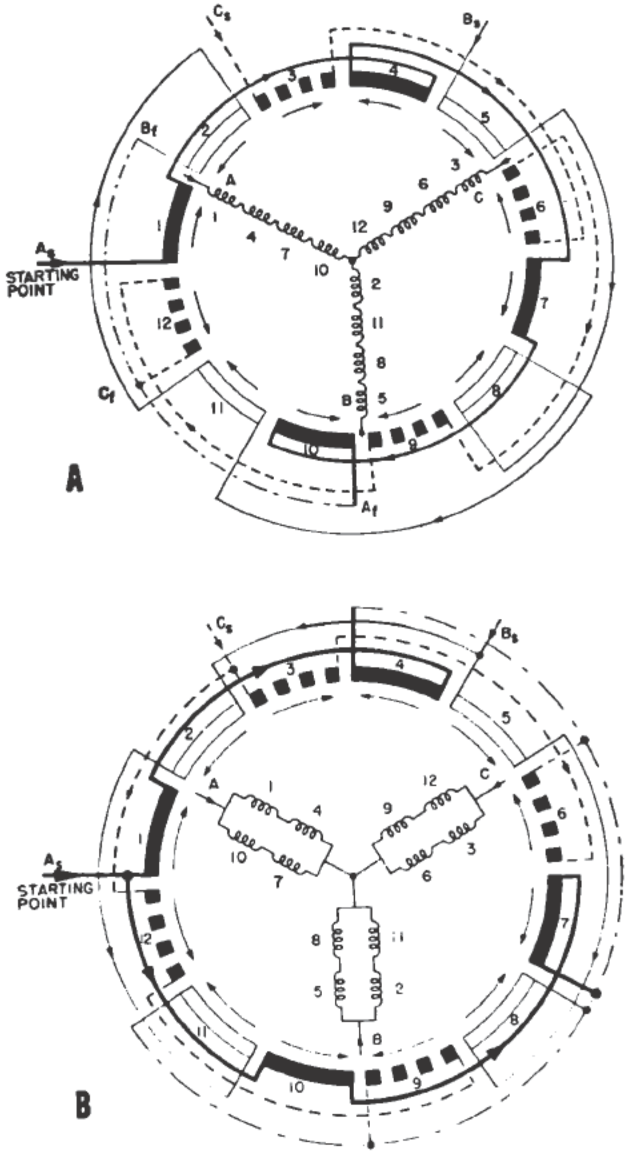


Figure 2-9.—Three-phase 4-pole Y windings: A, series; B, parallel.

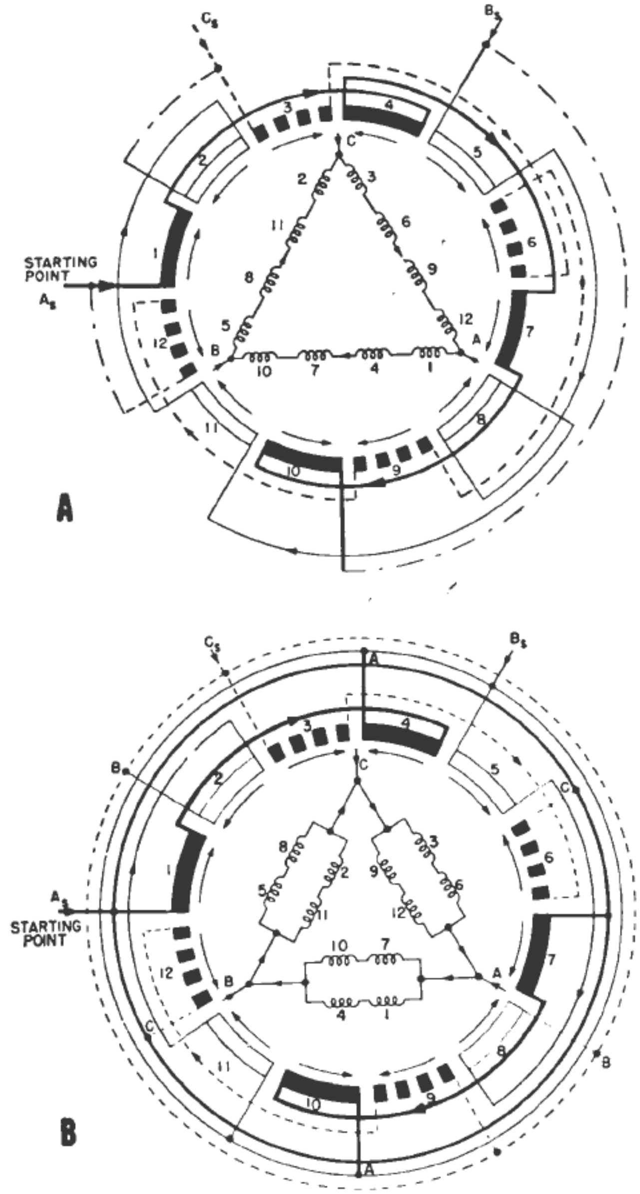


Figure 2-10.—Three-phase 4-pole delta windings: A, series; B, parallel.

the length of time taken by the rotor to pass through these electrical degrees, this becomes an accurate method of determining the out-of-timing of the voltages.

The distance between a north pole and a south pole, being one-half the complete revolution, is 180 degrees. The distance from a pole to a point halfway to the next pole is 90 degrees. If the coils producing the voltages are 90 degrees apart, a graph of the voltage shows the familiar sine-wave curve.

If you have a 3-phase motor, the voltages will be 120 degrees out of phase with each other.

The a-c induction motor has a current in the rotor that is induced by the magnetic field. The stator windings contain the three out-of-phase currents, and these establish a rotating magnetic field across the air gap. Attraction between stator and rotor poles produces the torque for starting the motor.

Remember, the rotors in this motor get current only by induction; there are no commutators or slip rings to feed current to the

rotor. Since there are no slipping contacts, there can be no sparks. In addition, there is less danger of the motor getting out of order.

Induction motors may be of the squirrel-cage or of the form-wound (wound rotor) type. The squirrel-cage motor has copper bars running the length of its iron core. These bars all end in copper rings; in this way, the rotor is certain to be a short circuit.

The form-wound type has the free ends of the rotor windings Y-connected to slip rings mounted on the rotor shaft. These slip rings, in turn, are connected to a variable resistor, or rheostat. At full motor speed, the rheostat cuts out, and the slip rings are short-circuited.

Both types of induction motor provide the three necessary factors for automatic starting of the motor: (1) voltage is induced in the rotor, (2) current flows in a shorted circuit, and (3) torque is produced by the magnetic field rotating on the inside of the stator.

The capacitor motor is a form of split-phase motor, with the addition of a capacitor (see the section, Electrical Terminology) connected in series with the starting winding. Current in the starting winding is 90 degrees out of phase with current in the running (main) winding. But the axes of the windings are also displaced by 90 degrees, and the starting torque thus produced is extremely high.

In some capacitor motors, the starting winding can be cut out after the motor has built up speed; in others, the starting winding and capacitor remain in the circuit. Direction of rotation of the motor can be reversed by interchanging the starting winding leads.

The repulsion motor develops starting torque through the interaction of the rotor currents and the stator field; but the stator field is a single-phase field, and induces rotor current only by its expansion and contraction. There would be no starting torque were it not for the commutator and brushes. The brushes are positioned so that they lie on an axis about 25 degrees displaced from the axis of the stator field.

Many of these repulsion motors are equipped with a centrifugal switch, which operates to lift the brushes off the commutator when 75 percent of full speed has been reached. This short-circuits the segments, and the motor thereafter runs as a single-phase motor. The advantage of this short-circuit device is that wear on the commutator and brushes is lessened by cutting them out as soon as they have served the purpose of starting the motor.

The one type of motor that will work on both a-c and d-c current is the Universal motor. This is also referred to as the a-c series motor, since its field and armature are connected in series. Since the field coils and armature coils are in series, they carry an identical current; and since they carry the same current, they reverse polarity at the same instant.

These motors are all of small horsepower, usually fractional horsepower. This type of motor is never built in a size of more than 1 hp, except for specially designed jobs.

The disadvantage of this type of motor is that the motor will race if load is removed, and the very high speed it may attain can damage the motor parts.

CIRCUIT PROTECTIVE DEVICES

Circuits in power distribution systems and in communications systems tend to become far more complex than the series and parallel circuits described here. Essentially, they are built up of series and/or parallel circuits, but the combination circuits and networks have their additional problems. Changing load demands can cause variations in current and in voltage drop throughout a system. Protective devices, therefore, have been developed, to ensure safe and reliable operation of the system. All service ratings should understand the various types of protective devices, and their uses.

Secondary Protective Device

Switches, fuses, and circuit breakers are the most usual type of protective device; however, switches are usually considered primarily as off-on devices.

SWITCHES serve as disconnectors in a circuit, and manually operated switches are placed in the leads to most equipment driven by electric power. A switch may also be installed to make it easier to short a circuit, as in the case of a repulsion motor.

When a switch is installed for any purpose other than as a simple disconnector, it must have a voltage and ampere rating suitable to the circuit on which it is installed. It is advisable to have it marked to show the amount of current that it can safely interrupt.

Where accidental opening or closing of switches could be a hazard, some suitable arrangement must be made for keeping them locked. This is especially important in the matter of remote-control switches.

Oil switches are usually supplied for major switching operations on a-c systems, where there may be considerable arcing. The oil quenches the arc, and in this way it keeps the contact points from deteriorating.

Protection from too high a current is provided by FUSES and CIRCUIT BREAKERS. In distribution systems, and in the equipment they service, fuses are installed so that when current exceeds a safe value, they will melt and open the circuit to interrupt current flow.

Plug fuses, which have a capacity up to 30 amp, are made for use in building lighting circuits. Cartridge fuses are made with capacities from 30 to 600 amp; for higher capacity circuits, knife-blade contact fuses are available.

Circuit breakers serve the same purpose as fuses, but they are generally installed in the large-capacity circuits, or in circuits that are frequently subjected to overloads. An oil switch in an a-c circuit, if provided with a relay for opening the circuit under overload conditions, becomes an automatic circuit breaker.

Primary Protective Devices

In addition to fuses, switches, and circuit breakers, you should understand the purpose of such devices as controllers, relays, and solenoids.

Manual adjustment of voltage on an a-c motor or generator may be possible when the load is fairly constant; however, load varies widely under practical operating conditions, and some automatic control is necessary.

The usual method of providing control is to use a rheostat, or variable resistor. Another type of variable resistor (a multitapped resistor) is sometimes used in place of a rheostat.

In the case of d-c generators, VOLTAGE CONTROL and voltage regulation are not the same thing. Voltage control refers to change in terminal voltage, when such change is brought about intentionally, with a field rheostat or similar apparatus. Voltage regulation refers to the maintenance of voltage throughout a system, by means of automatic controls called voltage regulators, where the characteristics of the generators cause changes in terminal voltage.

The voltage control, therefore, is always brought about by some device, operated either manually or automatically. A hand-operated field rheostat, or a tapped resistor, are the usual devices for raising or lowering terminal voltage.

RELAYS are used in connection with various control devices. They may operate by the rotation of a disk, which closes the contacts of a trip-coil circuit. Some operate by the pull of a plunger in a coil through which circulates a fixed proportion of the current in the circuit under control.

Relays can be used to control the opening and closing of remotely located oil switches and circuit breakers. In communications systems, they can be used to deenergize a circuit when grounding occurs.

LIGHTNING ARRESTERS provide for artificial grounding, as opposed to accidental grounding. A lightning arrester is a low-resistance path to ground for lightning, or for any abnormal electrical disturbance that would result in a dangerously high voltage between conductor and earth. Properly constructed, arresters will not pass very much current to earth during normal conditions. After an abnormal electrical disturbance has passed, they again provide a path to ground for normal leakage current.

QUIZ

1. Name 6 ways in which electrons may be put into motion.

2. Conductance is the term used to define the
   (a) intensity of electron flow through a conductor
   (b) space that lies in and around charged bodies
   (c) force that causes electron flow through a conductor
   (d) ability of a circuit to conduct current

3. The property of an electrical circuit that opposes change of current in the circuit is known as
   (a) capacitance
   (b) impedance
   (c) inductance
   (d) resistance

4. The watt is the practical unit for expressing the
   (a) intensity of current in a circuit
   (b) power made available by a circuit
   (c) energy stored in a circuit
   (d) energy made available by a circuit

5. What 3 factors does the text specify for a basic circuit?

6. What are the 3 normal sources of resistance in a circuit?

7. From the basic equation of Ohm's law, you can deduce that when resistance in a simple circuit is held constant, the result will be that
   (a) current will vary inversely with applied voltage
   (b) current will vary directly with applied voltage
   (c) voltage across the load will vary directly with the resistance
   (d) voltage across the load will be constant

8. Power delivered to a circuit always varies directly as the
   (a) square of the applied voltage, and inversely as the resistance
   (b) square of the applied current, and inversely as the resistance
   (c) square of the induced voltage
   (d) square of the current in the circuit

9. What is the fundamental difference between a series circuit and a parallel circuit?

10. What is Kirchhoff's law of voltages?

11. In a parallel circuit, how are the loads connected?

12. Total resistance in a parallel circuit is
    (a) less than the resistance of the smallest resistor
    (b) equal to the sum of the resistances of all the resistors
    (c) equal to the sum of all the resistances, divided by the number of resistors
    (d) less than the resistance of the largest resistor, but more than the resistance of the smallest resistor

13. Ordinarily, the rotating part of a d-c motor will be the
    (a) armature
    (b) field coils
    (c) frame
    (d) pole pieces

14. In a d-c motor, the magnetic field is produced by the
    (a) pole pieces and air gaps
    (b) magnetic circuit
    (c) electrical circuit
    (d) field coils

15. The strength of a motor can be increased by increasing the number of
    (a) lines of force that are cut
    (b) poles in the stator
    (c) windings in the armature
    (d) any of the above

16. The primary circuit in a motor is made up of
    (a) yoke, poles, pole windings, and field
    (b) commutator and sliding brushes
    (c) armature windings only
    (d) pole and armature windings

17. The external circuit of a d-c motor transmits electrical current directly from the
    (a) armature shaft
    (b) armature windings
    (c) brushes
    (d) yoke

18. The name given to the voltage induced in the armature windings as they pass through the magnetic field of the stator is
    (a) applied voltage
    (b) counter emf
    (c) effective emf
    (d) negative voltage

19. For what load condition are series motors best? Shunt and compound motors?

20. When the torque on the motor equals the resisting torque of the load, the result will be that the
    (a) motor will stop completely
    (b) speed of the motor will decrease slightly, until change of load occurs
    (c) speed of the motor will be constant until change of load occurs
    (d) motor will race, with danger to the motor parts

21. How is speed control obtained on a shunt motor?

22. In a d-c motor run as a generator, what is the direction of the current at the brushes?

23. What will be the effect of reversing the leads on a series motor?

24. The wiring diagram for a shunt motor shows that the field windings are in
    (a) series with the armature
    (b) series with the interpole
    (c) parallel with the armature
    (d) parallel with each other

25. Why is there a low limit on the voltage for an a-c motor designed with slip rings and brushes?

26. Why are the armature windings on most a-c synchronous motors placed in the stator?

27. How are single-phase windings connected?

28. How are 3-phase windings connected?

29. How does line voltage compare with phase voltage in a 3-phase motor with Y-connected armature? Line current with phase current?

30. What is meant by the term "phasing?"

31. In a 3-phase motor, voltages are out of phase with each other by a distance of
    (a) 30 electrical degrees
    (b) 60 electrical degrees
    (c) 90 electrical degrees
    (d) 120 electrical degrees

32. What are the 3 factors necessary for automatic starting of an induction motor?

33. Since a repulsion motor has a single-phase stator field, the production of a starting torque requires
    (a) interchanging the leads of the stator windings
    (b) interchanging the leads of the armature windings
    (c) positioning the brushes so that they are displaced 25 degrees from the axis of the stator field
    (d) positioning the brushes so that they are displaced 90 degrees from the axis of the stator field

34. Which type of motor can be used on a-c or d-c current?

35. Name 3 types of secondary protective devices for use in a circuit.

36. When a switch is used for any purpose other than as a simple disconnector, it is necessary that it be
    (a) installed at some remote location
    (b) installed so that it can be locked into position
    (c) of a voltage and current rating suitable to the circuit
    (d) all of the above

37. What type of variable resistor is sometimes used in place of a rheostat?

38. In the case of d-c generators, what is the distinction between voltage control and voltage regulation?

CHAPTER 3

DIAGRAMS AND SCHEMATICS

EVERY MAN who is preparing for any of the Construction Electrician service ratings must know how to make mechanical and soldered connections, how to splice wires, how to climb poles, and how to make minor repairs to electrical wiring and electrical fixtures.

EVERY SYSTEM of wiring is installed and connected according to definite plans and specifications. There must be a plot plan which gives the whole layout; this plan is in the form of a large blueprint, bearing a title block that gives all the data necessary to identify the plan. These blueprints usually carry explanatory notes, and references to "details," or additional drawings which represent portions of the plot plan in greater detail.

Before you can work safely and efficiently on any part of an electrical system, it is absolutely necessary that you know how to read blueprints. You must understand the different parts of a drawing, know how to work from a plot plan to a detail blueprint, and know the meaning of electrical symbols.

In addition to the plot plan, which in most cases shows the layout of an entire installation (fig. 3-1), and the detail drawings (fig. 3-2), which might carry such information as locating poles, guying them, installing lightning arresters, and so on, there will be other drawings known as wiring diagrams. These diagrams and schematics show the wiring plans for individual buildings, and serve as guides for installing individual systems and equipment, and for making repairs.

This chapter provides you with the basic information needed for understanding blueprints and wiring diagrams for simple electrical systems, and for such equipment as universal motors, shunt motors, and series-shunt motors.

BLUEPRINT READING

The most important reference book for Navy men who need to know about blueprints and blueprint reading is the Basic Navy Training Course, *Blueprint Reading and Sketching*, NavPers 10077-A. This is one of the texts included in the Reading List in the front of this training course.

The basic course in blueprint reading, however, was planned to meet the needs of several different Navy ratings, and no one trade or technical field can be developed in great detail. Therefore, this chapter in Construction Electrician is intended to supplement the chapter, Electrical and Electronics Blueprints, in NavPers 10077-A.

Types of Drawings

The term "plan" is frequently used, in a loose sense, to mean any drawing that is provided as a guide to any part of a construction job. Strictly speaking, a plan drawing is one that shows the objects or parts positioned in relation to one another; further, it is always a view from directly above the objects or parts. It is as if they formed a sort of floor plan, spread on a flat surface, and viewed from above. This arrangement is clearly the one indicated in figure 3-1.

Other blueprints may show elevations—the object as viewed from front, side, or rear. Objects are shown in true relation to each other. In figure 3-3, you will see the method in which front, rear, and side elevations of a building can be shown. Any part (for example, the right-hand section of the front elevation) can be reproduced on a larger scale, and in much greater detail. This latest drawing is then known as a detail drawing, and a reference to it would occur in the related section of the front elevation drawing.

Sometimes a sectional view is necessary, where it is impossible to convey full details on the elevation drawing. The sectional view is a cutaway view, showing shape and construction at the cutting plane.

Drawings may be either perspective, isometric, or orthographic. These types of drawing may be briefly described as follows:

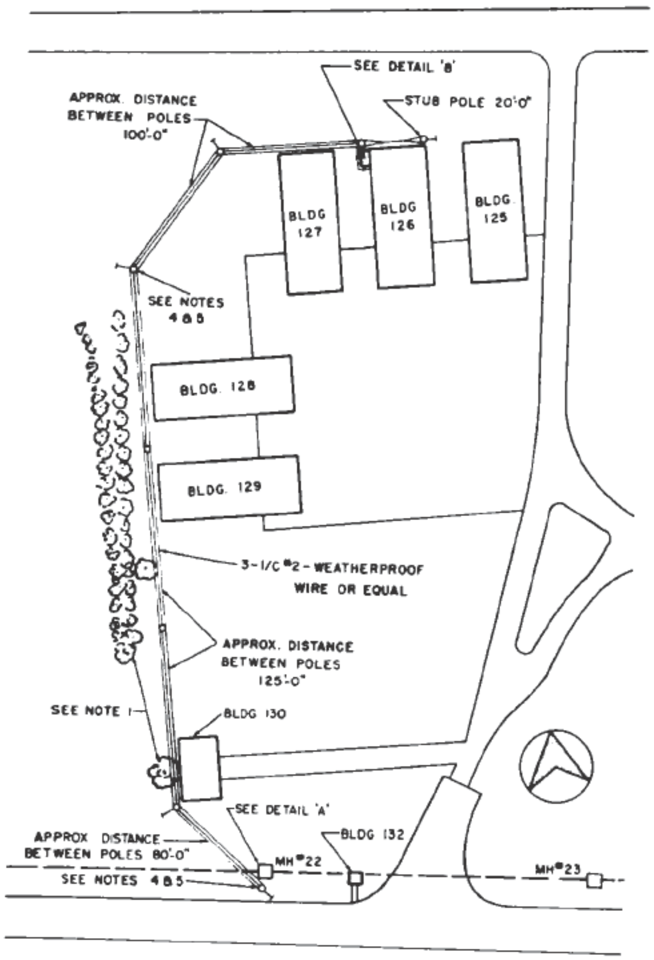


Figure 3-1.—Plot plan.

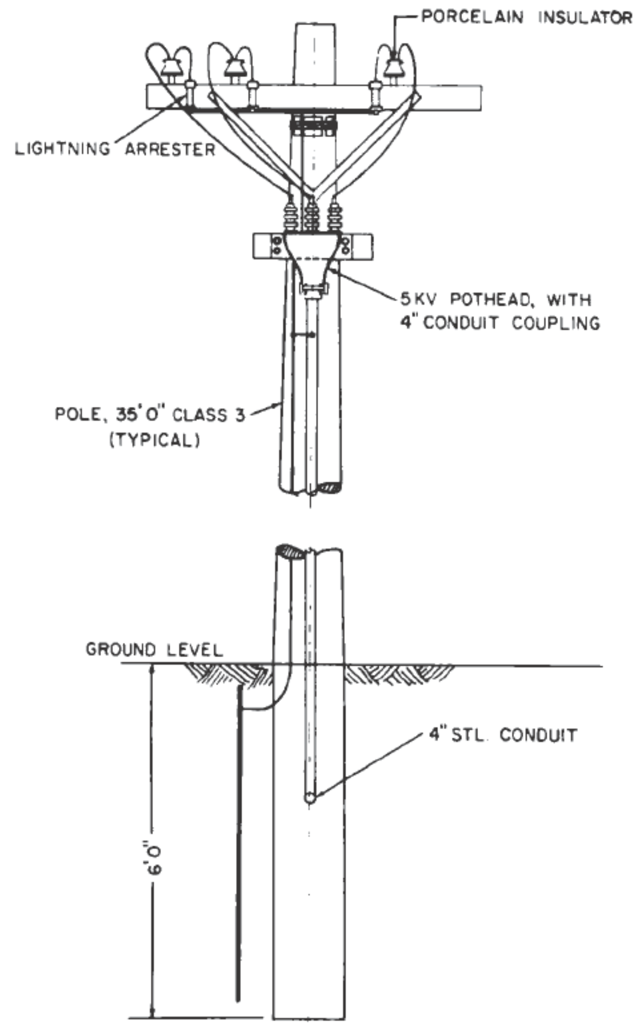


Figure 3-2.—Detail drawing.

A PERSPECTIVE drawing represents an object or a scene just as it appears to the eye. Size of objects in middle or far distance is less than that of similar-sized objects in the foreground. To give a sense of distance, lines that actually are parallel to each other are shown as slightly converging.

An ISOMETRIC drawing is similar to a perspective. The chief difference is that all objects are drawn to scale in all respects-the meaning of isometric is, in fact, "equality of measure" or identity of scale. Thus two objects of the same measurements would be drawn to exactly the same scale, even though one was located 100 feet to the rear of the other.

An ORTHOGRAPHIC drawing is one in which the lines of projection are all perpendicular to the plane formed by the drawing paper. It is as if you took an open box, cutting away one side and one end; on the bottom of the box is the base or floor plan, on the remaining side is the side elevation, and on the remaining end is the end elevation. Thus the floor plan is in the horizontal plane, the side elevation in a plane vertical to the horizontal, and the end elevation in a plane vertical to the horizontal plane and to the first vertical plane.

This type of projection, while common enough in mechanical drawings, is not one with which the Construction Electrician will be likely to work.

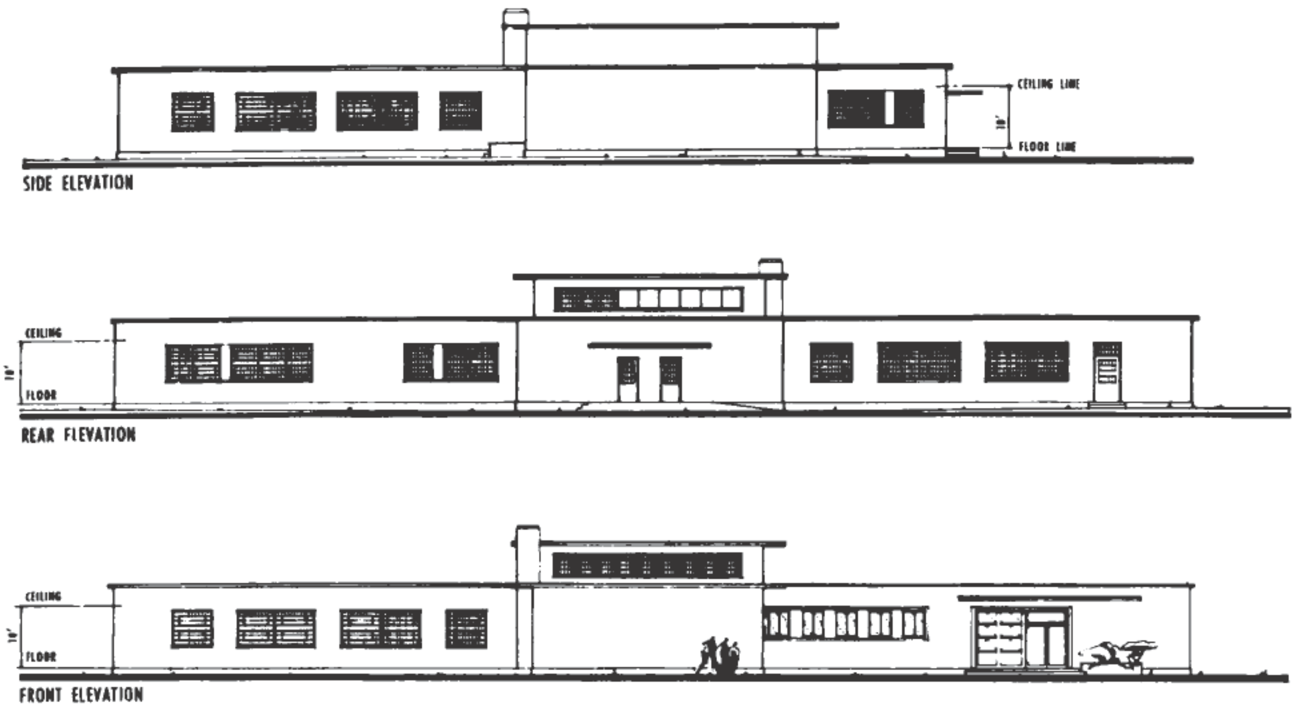


Figure 3-3.—Typical elevation drawings.

Parts of a Drawing

The chief part of a drawing is, of course, the plan, whether plot plan, elevation, section, or detail. On this are the lines, the dimensions, and the symbols which form the language of the blueprint. However, certain additional information will usually be necessary, and this you will find in the title block, the bill of material, the scale, and the legends and notes.

The BLOCK gives the title of the drawing, and the number that has been assigned to that drawing. It indicates also who prepared the drawing, who checked it, the authority under which it was issued, and the date approved.

The number is especially important, both for purposes of filing the blueprint, and for locating the correct drawing when it is specified on another blueprint that the wiring system shall be installed in accordance with that shown on such and such a drawing number. Where a number of separate buildings, shown on a series of blueprints, are to have identical wiring systems, cross-referencing them to the number given one building saves the labor of repeating the wiring system on every drawing.

Figure 3-4 is a copy of the title block appearing on a drawing for a hut camp layout at an advanced base. The drawing from which this block was taken, like most of the drawings used by the Construction Electrician, was prepared at the Bureau of Yards and Docks.

The BILL OF MATERIAL is a list of all the items required to install a particular piece of equipment or to erect a particular building. These lists include stock number, description, and quantity of each item. As you can see, by referring to figure 3-5, the list is complete down to the last screw and washer. The item numbers in the first column refer to the drawing, and make it easier to identify each item, its location in the blueprint, and its purpose or function.

When equipment assemblies are received at an advanced base, it is possible for you, by checking the bill of material, to quickly determine if the items shipped are what you need for the job in hand, and if they allow for changes made necessary by local conditions.

The SCALE of a drawing is particularly important to the construction men, but it has a practical value to the Construction Electrician,

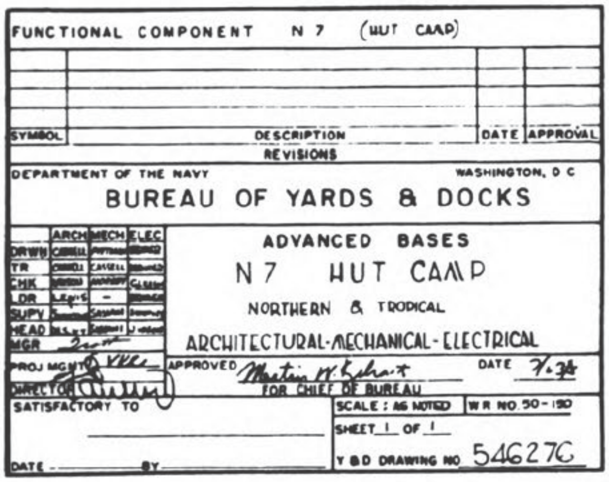


Figure 3-4.—Title block from a BuDocks drawing for an advanced base hut camp.

also. Dimensions of buildings, and distances between them, will have to be considered in figuring the number of reels of wire required, and the number of poles to be erected.

The NOTES AND LEGENDS which you can expect to appear on a drawing are illustrated in figure 3-6.

The notes contain equipment specifications, procedures for installing, and operating instructions. They may also contain explanations of parts of the drawing, and other types of pertinent information not included in the blueprints.

The legend lists the meanings of the various symbols, abbreviations, and item numbers. This is a great help to the various ratings that may be engaged in the work, since not all of them would know the symbols well enough to immediately grasp the overall plan for the construction job.

You will find legends of great help when the drawings relate to a job where plumbing fixtures, valves, duct work, or pipelines must be considered when you are planning the laying of conduits or the running of wires.

Bureau of Yards and Docks Drawings

As mentioned before, the Construction Electrician very often works from a drawing prepared by the Bureau of Yards and Docks. Construction Battalions seldom have the time or the facilities for preparing sets of blueprints.

BILL OF MATERIAL

ITEM NO.	DESCRIPTION	STOCK NO.	QUANTITIES	
			TROP.	NORTH.
1	SWITCH, SAFETY, 200 AMP, 250 VOLT, 3 POLE	3E17-16	1	1
2	FUSE, RENEWABLE, 200 AMP, 250 VOLT	3E18-23	6	6
3	LINK, FUSE, 200 AMP, 250 VOLT	3E19-14	25	25
4	RACK, SECONDARY -	3E15-14	11	11
5	CLEVIS, INSULATED	3E36-3	30	30
6	WIRE, 1/C NO. 14, TYPE "R"	3E10-4	1600'	1600'
7	CABLE, 1/C NO. 6 DIRECT BURIAL	3E10-24	850'	850'
8	CABLE, 1/C NO. 1, DIRECT BURIAL	3E10-36	600'	600'
9	CONNECTOR, CABLE, BURNDY NO. KS-25	3E14-31	75	75
10	TAPE, FRICTION, 1/2 LB. X 3/4" ROLLS	3E25-3	14	14
11	TAPE, RUBBER, 1/2 LB. X 3/4" ROLLS	3E25-4	10	10
12	SCREW, LAG, 1/4" X 1 1/2"	7D48-292	4	4
13	WASHER, F/1/4" SCREW	3D46-34	4	4
14	SWITCH, SAFETY, 30 AMP, 230 VOLT, 3 POLE	3E17-12	6	6
15	SWITCH, SAFETY, 60 AMP, 230 VOLT, 3 POLE	3E17-15	3	3
16	SWITCH, SAFETY, 100 AMP, 230 VOLT, 3 POLE	3E17-45	1	1
17	FUSE, CARTRIDGE, 30 AMP, 230 VOLT	3E18-14	40	40
18	FUSE, CARTRIDGE, 60 AMP, 230 VOLT	3E18-17	20	20
19	FUSE, CARTRIDGE, 100 AMP, 230 VOLT	3E18-21	10	10
20	LINK, FUSE RENEWABLE, 30 AMP, 230 VOLT	3E19-4	100	100
21	LINK, FUSE, RENEWABLE, 60 AMP, 230 VOLT	3E19-8	100	100
22	LINK, FUSE, RENEWABLE, 100 AMP, 230 VOLT	3E19-12	50	50

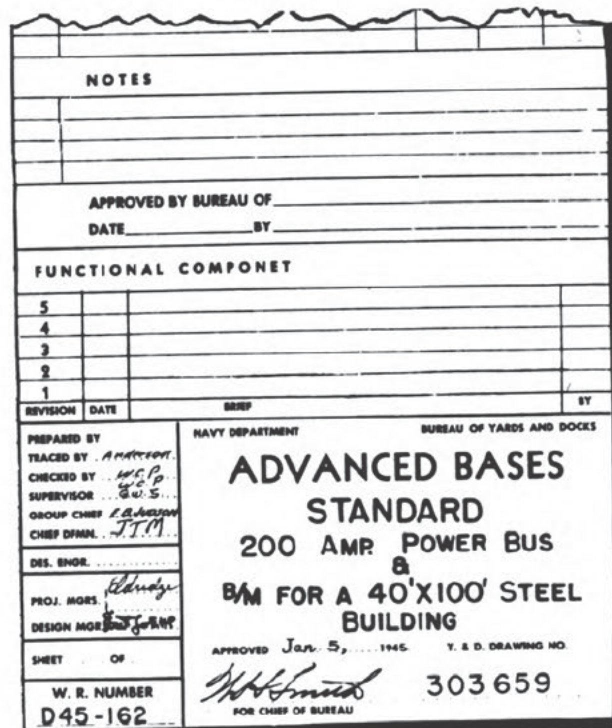


Figure 3-5.—Bill of material.

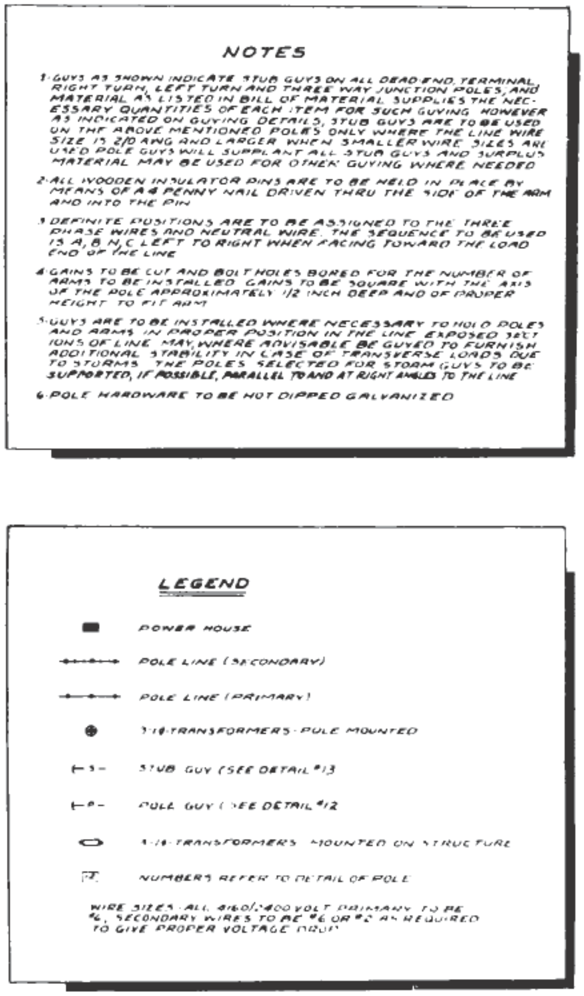


Figure 3-6.—Notes and legends.

For this reason, BuDocks has prepared a series of drawings for use at advanced bases. These drawings cover every type of major installation. Copies are made available to all battalions before they leave the United States.

This set of drawings is entitled *Advanced Base Drawings*, NavDocks P-140, and is kept in the operations or engineering office. A complete drawing is usually composed of a number of separate drawings; the specific information which they furnish on proper installation of equipment, and operating procedures, will furnish satisfactory answers to many installation problems.

These standard drawings prepared by BuDocks can save a surprising amount of time in the erection of similar structures, and in wiring them for heating and lighting. For example, if a series of quonsets are to be erected, use of a standard plan enables the construction men to put the various tasks on an assembly line basis, and makes it possible to erect an entire quonset town in less time than it would normally take to build an ordinary house.

However, a single master plan cannot be used for all buildings, since changes are often necessary because of the use to which a building may be put, and the type of machinery to be installed. Where shops are being erected, there will probably be at least one standard drawing prepared for each type of shop.

Whatever the number or type of drawings available, they must furnish the Construction Electrician with the following information: layout and space arrangements; necessary machinery, equipment, and materials; list of any reference drawings; and notations about changes made in standard drawings, to fit the particular building.

ELECTRICAL SYMBOLS

The number of symbols and of abbreviations that may be used on drawings runs into the thousands. All draftsmen do not employ the same symbol to represent a particular item. These two facts can make blueprint reading a major task for any rating.

Fortunately, however, a military standard has been issued, to bring about a high degree of uniformity in the drawings provided for the men in the armed services. MIL-STD-15A, *Electrical and Electronics Symbols* (dated 1 April 1954), shows the symbols required for use in the field of electricity and electronics. Since 1 May 1954, the Departments of the Army, the Navy, and the Air Force have required the use of these symbols. Similar standards have been issued to cover architectural, mechanical, structural, and welding symbols.

Other standards that you should be familiar with are:

MIL-STD-12A, *Abbreviations for Use on Drawings* (11 March 1952).

MIL-STD-16B, *Electrical and Electronics Reference Designations* (1 June 1956).

MIL-STD-103, *Abbreviations (for Electrical and Electronics Use)* (18 May 1953).

The standard identified as 12A contains a list of those abbreviations which are customarily

used on all types of drawings. MIL-STD-103 supplements 12A, by establishing a more complete list of standard abbreviations to be used on electrical and electronics drawings.

The reference designations given in MIL-STD-16B are combinations of letters and numbers. These designations are used to identify parts, subassemblies, and units on drawings or diagrams of equipment. The letters indicate the type of part—that is, resistor, electron tube, coil, and so forth; or else they identify a subassembly. The number part of these designations serves to distinguish between parts or subassemblies of the same class.

All of the references listed above should be available to you at your base. In addition, figure 3-7 gives you a list of symbols that you can use for ready reference. These symbols have been chosen to include the ones most commonly used in electrical work; there are, of course, many more that would be helpful to you, but space will not allow for reproducing any great number of symbols in this training course.

You should learn these symbols, and as many others as possible, for there will be many times when you will have to interpret a symbol on a drawing, without the aid of this figure as a reference.

Take every chance you get to study the blueprints of the jobs to which you are assigned. Try to picture in your mind the item represented by each symbol. Trace the electrical circuits until you understand the location of the various parts, and their importance to the complete job. When the lines, symbols, abbreviations, and notes make a definite and understandable pattern to you, then you have the satisfaction of knowing that you are able to take a blueprint and use it as a guide to do a job properly.

WIRING DIAGRAMS

The buildings upon which you will work will be wired with copper wires, or conducting cables; rubber or fabric covering provides for insulation. In temporary buildings, the conductors are usually BX cable (metallic sheath cable), or Romex (nonmetallic sheath), and they are supported by strapping or stapling. For the more permanent type of insulation, the conductors run through metal conduits. The CONTINUITY of the conductors is accomplished by splicing them, or by tapping them into a junction or outlet box.

Switches are installed at various places in any system, to control the flow of current. Metal or bakelite outlet boxes are installed where lights and appliances are to be connected to the system. These boxes may be surface mounted, or they may be subsurface (flush) mounted. The outlets are usually wall receptacles, into which the plug on the fixture or appliance cord can be inserted. On the other hand, they may sometimes be screw-base units, as for ceiling lights.

A diagram of the wiring system that is to be installed will show the materials specified, and the switches, taps, and outlets to be installed.

Elementary Diagrams

Elementary diagrams that you will use for working on systems or equipment will show the circuits; whether circuits are series or parallel; voltage; phase, if a-c current is used; and such other details as outlets, switches, panels, feeders, junctions, and branch circuits.

Any drawing that is titled a WIRING DIAGRAM will almost certainly have one or more of three distinctive features. One feature is the indication of the various terminal connections, as shown in figure 3-8. A working drawing for this wiring diagram is shown in figure 3-9.

The second feature typical of many wiring diagrams is that machines, parts, and various other items are shown in about the same positions as they will actually occupy.

The third feature is that some of the items are represented, not by the standard electrical symbol, but by actual shape or appearance. Figure 3-10 shows all of these distinctive features occurring in a single diagram.

The BLOCK diagram is another type of wiring diagram which you will frequently use. As you can see from figure 3-11, it gives an overall picture of the functioning of some piece of electrical equipment. A single line tying together the different parts, and carrying arrowheads to indicate the sequence of operation, makes the various phases easy to understand. The use of diagrams such as this can eliminate the need for drawing hundreds of wires and connections.

Schematics

Schematics of systems or equipment are used as guides for making new installations, or

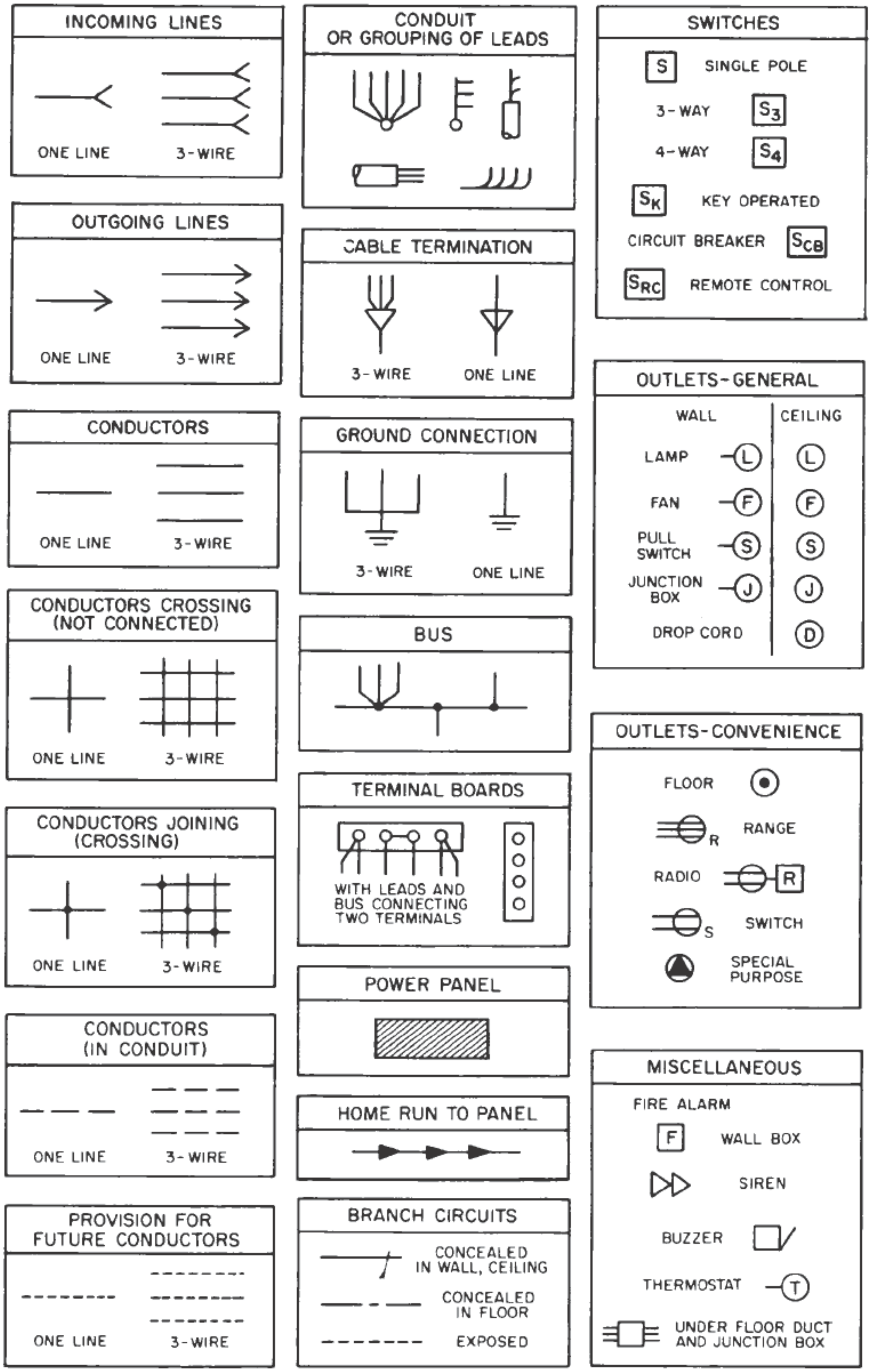


Figure 3-7.—Symbols commonly used on electrical drawings.

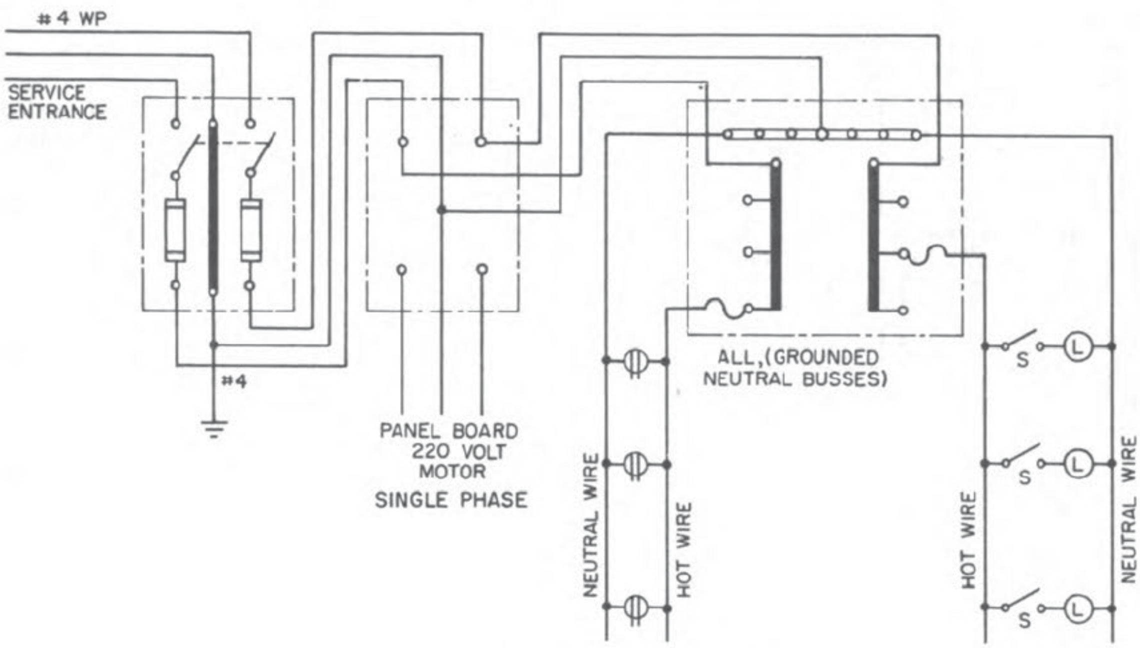


Figure 3-8.—Interior wiring diagram.

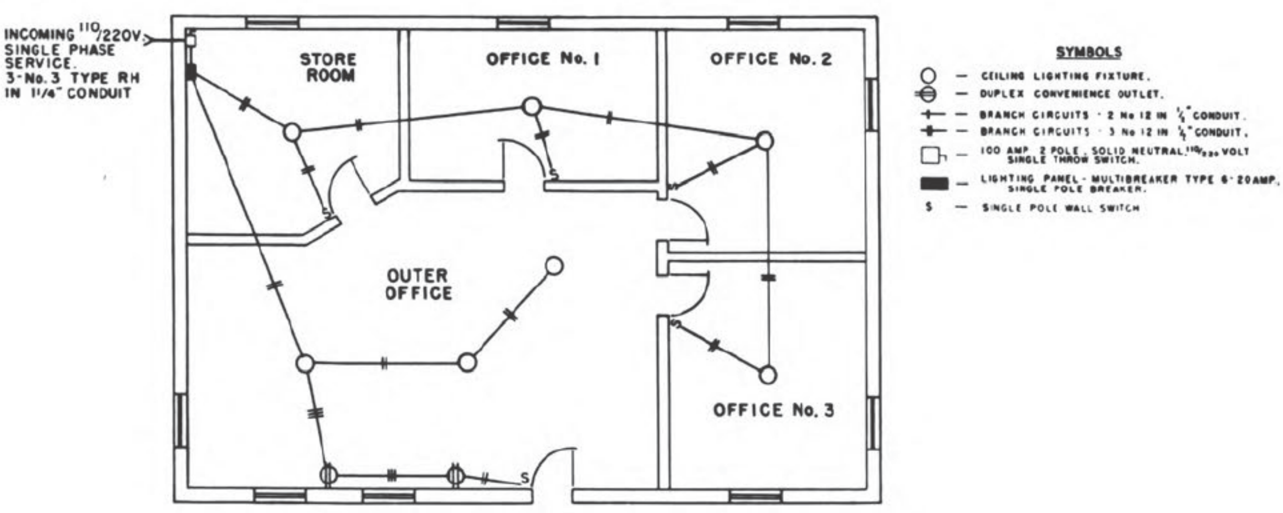
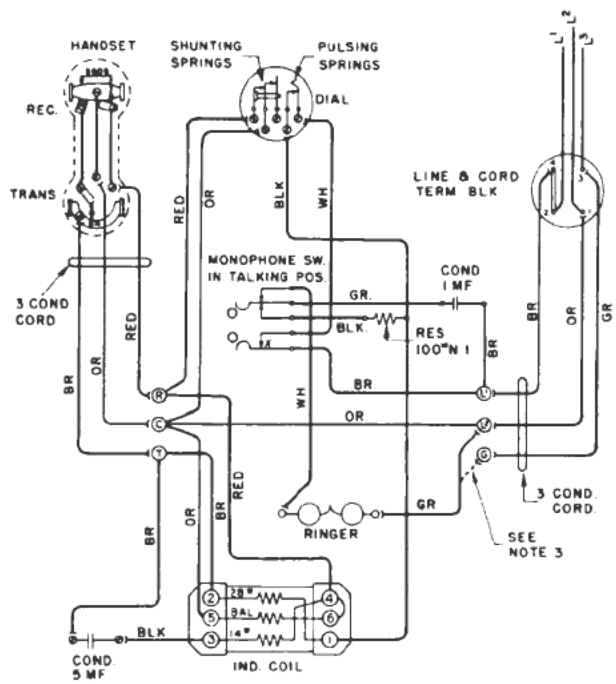


Figure 3-9.—The electrical plan.



NOTES:

1.- IF BELLS TAP WHEN DIALING FROM ANOTHER TELEPHONE ON THE LINE, REVERSE CONNECTIONS AT THE RINGER.

2.-"X" CONTACTS TO BREAK FIRST AND MAKE LAST.

3-FOR METALLIC RING, CONNECT GR RINGER WIRE TO TERM L^2. FOR GROUND RING, CONNECT TO TERM G

Figure 3-10.—Typical wiring diagram.

repairs on existing ones. Symbols are used throughout these drawings, and the location of the various parts bears no relation to their actual location.

Figure 3-12 illustrates a schematic diagram of an intercom unit. If you study this figure, you will realize how the use of symbols, and the disregarding of true locations, has resulted in condensing this drawing so that the circuits can easily be traced. Schematics such as this one are extremely useful when you must do trouble shooting on switchboards, radios, and other circuits containing a great number of wires.

The basic information given in this chapter should enable you to understand plot plans, layouts, and wiring diagrams from which you will later have to work. Additional diagrams and schematics are used throughout this training manual, in connection with the descriptions of specific equipments.

REPAIRS TO WIRING SYSTEMS

A discussion of repairs to wiring systems is something that all Construction Electrician service ratings should read and study. This material might well be spread throughout the text; or it could be discussed in the chapter on wiring, or in the chapters dealing with communications systems, power distribution, and shop work. However, since this present chapter is one that must be studied by all CE service ratings, and since in the preceding section, Schematics, we have mentioned the need of diagrams as guides in making repairs on systems and equipments, it will not be out of place to include on-site repairs to wiring and fixtures as the final section in this chapter.

Types of Repairs

Practically all trouble calls on an interior wiring system will involve shorts, grounds, or open circuits. A shorted circuit is probably the most frequent type of difficulty. The open circuit is indicated when current is not reaching a point where it is needed; a blown fuse (while it may mean an overloaded circuit) usually indicates either a short or a ground.

A fuse blows; it is replaced by another fuse, and the second one blows. In most cases, this is a sure indication that a short or a ground is causing the trouble; if the difficulty were caused by an overload, the fuse would heat gradually, and then burn out.

A visual check of the defective circuit may be all that is needed to locate the source of trouble. Perhaps some equipment has been pushed against the line; or a connection may have started smoking, or sparks may have been jumping from a box, just before the fuse blew. If a visual check, and questioning of personnel who have been using the circuit, cannot pinpoint the trouble, you will have to dig into the circuit.

You know that this branch circuit consists of two wires, the black (hot) one, and the white (ground) one. Normally, the current will pass through every fixture and every piece of equipment connected into the circuit. When it fails to do so, your first thought should be that a short exists somewhere between the panelboard and the faulty equipment or fixture. Essentially, all you have to do is to disconnect the wires systematically, until the short circuit current is cut off.

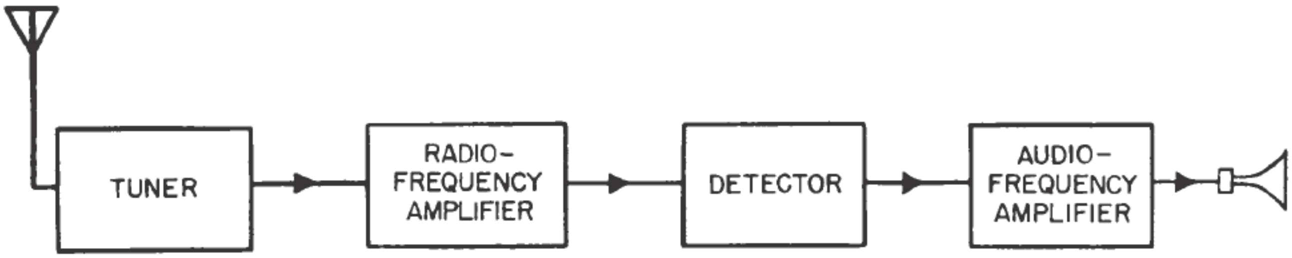


Figure 3-11.—Block diagram.

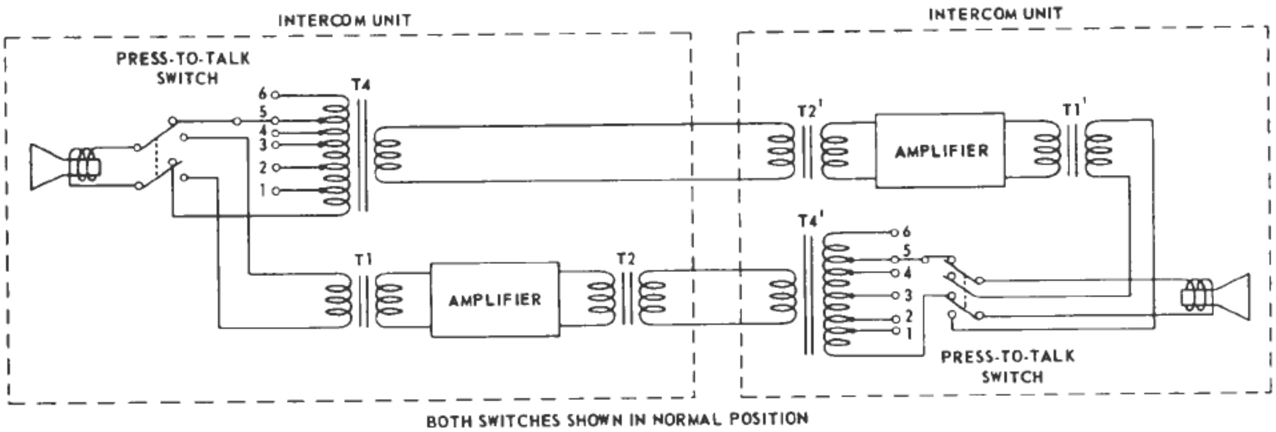


Figure 3-12.—Schematic of an intercom unit.

Testing Devices

A test lamp or some similar testing device is necessary to test a circuit. Two light bulb sockets wired in series (fig. 3-13) provide a simple tool for testing. Screw a 110-volt light bulb into each socket. The current, in order to flow, must pass through both bulbs.

When placed in a 110-volt circuit, the lamp burns, but not with full brilliancy. When placed in a 220-volt circuit, the bulbs burn with normal brilliancy. This device, therefore, indicates whether current is flowing in the circuit, and helps you to determine two different voltage ranges.

To locate the trouble, disconnect both the black wire and the white wire from the source of power, at the panelboard, and replace the fuse. Let one lead of the test lamp contact the fuse block (or switch box), and the other lead contact the black wire. If the trouble is a GROUND, the bulbs will light; in this case, you must NOT reconnect the black wire, else you may blow the new fuse.

If the lamp does not light, you know that the trouble is a short, and you can safely reconnect the black wire. Make doubly sure that there is a short by checking to see if the bulbs in the test lamp light when one lead of the lamp is touching the ground terminal, and the other lead touches the white wire.

Your next step is to find out where the short occurs. Turn off all switches in the circuit, and disconnect all plugs from the outlets and receptacles. Check again at the panelboard to see if your test lamp lights. In almost all cases, it will not, and you know that the short is in a fixture or in some piece of equipment.

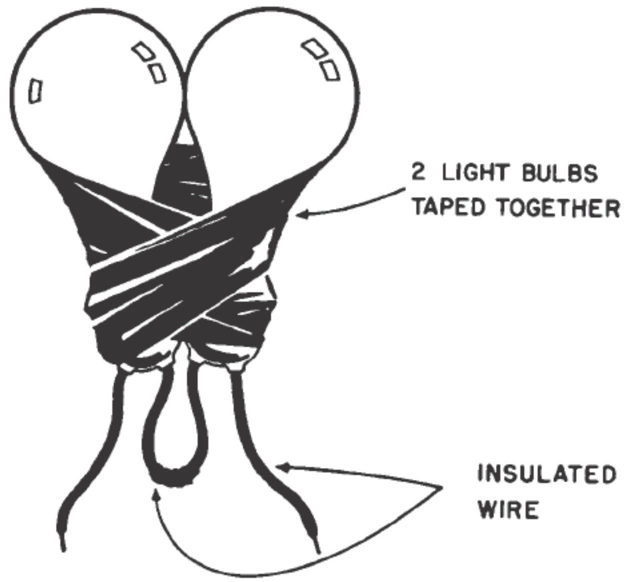


Figure 3-13.—Test lamp.

Cut each fixture and equipment back into the circuit, one by one, until you locate the spot at which the short exists.

Occasionally, it will happen that when you have opened all the switches in the circuit, and disconnected all the plugs, your test lamp will light when you make the check at the panelboard. This indicates that the short is in one of the junction boxes. (It could be within the conduit itself, but this is an extremely unlikely case, and a check on the conduit should never be made until all other possibilities have been checked.)

Use the greatest caution when you must check junction boxes. BEFORE YOU DISCONNECT OR CONNECT ANY WIRE, KILL THE CIRCUIT BY REMOVING THE FUSE.

If you start at the middle box in the defective circuit, you can automatically eliminate half the circuit. First disconnect the black and the white wires, replace the fuse, and then use the test lamp to check between the white wire and the ground terminal at the panelboard. Two or three check points should pinpoint the trouble spot.

You will probably discover that the cause of the short was a careless job of taping the wires, on the part of the men who wired the building. Remember this when you are engaged in installing a wiring system, and lessen the chances that some other Construction Electrician will have to locate shorts caused by carelessness on your part.

Testing to locate a ground calls for a similar procedure. Remember, you disconnect the black and the white wires at the panelboard, and then place your test lamp between the fuse block and the black wire. If the bulbs light, there is a ground in the circuit. As with the search for a short, you reduce the circuit into smaller and smaller sections, until you have located the section where the ground occurs.

As mentioned before, failure of current to reach any point in the circuit means an open circuit—that is, a break in the line. This is the easiest type of trouble to locate. With your test lamp, start checking from the center of the circuit. Where the bulbs light, the circuit is good. Usually, a check of just a few points will show you where the fault lies. And the cause of the break will almost certainly be an improperly soldered wire connection.

Besides the test lamp, there are a number of testing devices that can be used in determining shorts and grounds. The lamp has the advantage that you can make it yourself, when necessary. Another simple device is a bell and battery; if the circuit is faulty, the bell will not ring.

Simple mechanisms that will probably be available are the Wigginton voltage tester (Wiggins), an ohmmeter, or a megger.

The Wiggins is a small instrument calibrated to show either a-c or d-c voltage. It is fitted with two prods, one red and one black. When the prods are inserted in a receptacle or outlet, a small metal pointer moves downward in the slot between the two voltage scales. The prods are sharp-pointed, so that they can be pushed through the insulation of a conductor, to touch the wire itself.

An ohmmeter is a voltmeter with resistance and battery in series with the meter coil. The battery furnishes a small voltage, just enough to cause full-scale deflection of the meter scale when the test prods are touched together. If an added resistance is introduced between the prods, there will be a corresponding reduction in current; and with reduced current, the meter scale will read less than full deflection.

The megger is equipped with its own small d-c generator as a source of power. The reading on the megger shows whether the circuit is in good operating condition.

Ohmmeters and meggers are described at greater length in the following chapter, Chapter 5 Meters and Controls. From the brief description given here, however, you can see

that these two devices, and the bell and battery, furnish their own power. This means that they can be used to test circuits in interior wiring after the installation has been made, and before the connections have been made to the power distribution system. The Wiggins and the test lamp, on the other hand, can be used only for testing circuits connected to a power source.

QUIZ

1. A plan drawing is one that shows the objects or the parts as if viewed from directly above and
   (a) showing shape and construction at cutting planes
   (b) indicating the various elevations
   (c) drawn to show complete details
   (d) positioned in relation to one another

2. Which is the type of drawing that shows all objects drawn to scale in all respects?

3. The part of a drawing in which you will find procedures for installing and operating the subject equipment is the part known as
   (a) the bill of material
   (b) detail drawings
   (c) notes and legends
   (d) the title block

4. To save time needed for erection and wiring of structures at advanced bases, BuDocks drawings are made available in what publication?

5. What publication shows the electrical symbols required for use by all departments of the armed services?

6. The electrical symbol $\ominus_{R}$ indicates a
   (a) radio outlet
   (b) range outlet
   (c) fire alarm siren
   (d) remote control switch

7. The electrical symbol  indicates a
   (a) cable termination
   (b) ground connection
   (c) incoming line
   (d) outgoing line

8. What are the 3 distinctive features of wiring diagrams?

9. What type of wiring diagram gives an overall picture of the functioning of a piece of electrical equipment?

10. On schematics of systems or equipment, the location of the various parts
    (a) bears no relation to true location, and the parts are identified by shapes
    (b) bears no relation to true location, and symbols are used for identification
    (c) corresponds approximately to true location, and symbols are used for identification
    (d) corresponds approximately to true location, and arrowheads indicate sequence of operation

11. What indicates an open circuit in a wiring system? A short or a ground?

12. What elementary precaution must you always take before testing for a short in a junction box?

13. What 3 devices listed in the text can be used to check a circuit that has not yet been connected to the power distribution system?

CHAPTER 4

WIRING

At any Navy base, the electrical system will consist of three separate parts: the power plant, that supplies the electricity; the wires of the distribution system, that carry the electricity across the gaps between the generating station and the various buildings; and the interior wiring systems, that feed the electric power to appliances and equipment within each building.

Responsibility of the CEW rating for the installing of wiring in a building begins at the outside of the building, at the point where the wiring system connects to the service leads from the distribution system. It continues down through the last branch circuit, and the last fixture installation.

The wiring system must meet two requirements: it must be safe, both for personnel, and for the appliances that it serves; and it must be capable of lasting as long as it is needed.

All electrical installations must conform to the standards of the National Electrical Code, and to the specifications established in *Electrical Apparatus Distributing Systems, and Wiring*, NavDocks Specification 9Y.

The wire used must be of the proper size, and it must have a protective covering. Conductors must not be exposed to unduly high temperatures; rated carrying capacity of each size of wire is based on the assumption that 86 F will be the usual temperature around the installation. In general, a temperature of 140 F should be considered maximum for rubber-covered (R-C) wires, although higher temperatures are safe for wires covered with varnished cambric and installed in dry locations, and for thermoplastic-covered and asbestos-covered wires used in switchboards.

Switchboards with live parts must be located in places that are permanently dry, and must not be in contact with material that could readily catch fire.

The system must be properly grounded, and the right types of fuses, switches, and circuit breakers must be installed, to control and protect the equipment connected to the wiring system.

INSTALLATION OF INTERIOR WIRING SYSTEMS

From your study of the preceding chapter, you know that you can depend upon the BuDocks publication, *Advanced Base Drawings*, NavDocks P-140, to provide you with a wiring diagram for almost any type of advanced base installation. However, in the event that no diagram is available, or that you must make changes in an existing drawing in order to provide for special conditions, you should carefully prepare your own diagram before beginning any of the actual work of installation.

Unless you have a very clear idea of the overall electrical layout, you can easily take a wrong step at the very beginning of your job. The number of service conductors, and the size of the wire that you will use, must be determined from the load that is to be accommodated. Then, too, you should know beforehand the number and location of all switches, fuses, breakers, outlets, branch circuits, and so forth, that are to be installed as part of the interior wiring system.

To include all this information on one plan would result in a very complicated drawing. It is customary to have the overall plan show only the location of the service conductors and the necessary connections to the interior wiring; figure 4-1, for example, is this type of plan. Then a supplementary floor plan, such as figure 4-2, shows the location of fixtures and equipment.

Service Entrance

The service conductors are the electrical power supply conductors leading from the power distribution system (transformer or main) to the service equipment of the premises. For overhead cables, these conductors will be between the last pole in the distribution system and the connections on the outer wall of the building. (This portion between the service pole and the point of attachment to the building is also known as the service drop.)

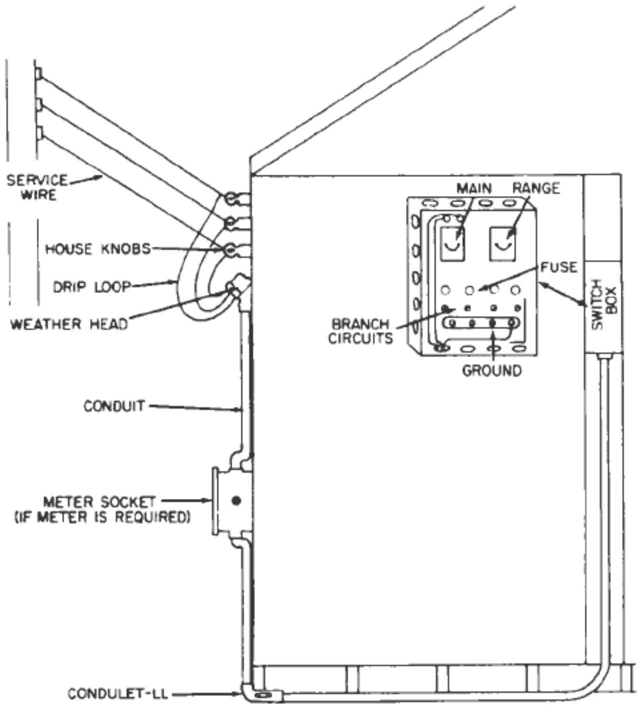


Figure 4-1.—Connections to service leads, and to interior circuits.

When underground conduits must be used for service into a building, the underground portion must be encased in a noncinder concrete envelope with a wall thickness of at least 3 inches. The conduit must be of rigid steel to a point 5 feet beyond the building and the projections thereof. At this point, there should be a manhole for drainage. For conduits not extended beyond this point, threaded metal caps must be provided for the ends, and the threads should be coated with graphite grease, or a similar coating.

Where a conduit is brought into the building through a concrete floor, take care that the curved portion is not visible above the finished floor. The concrete envelope that encases the conduit should extend throughout the space between the floor and the foundation wall. For underground service connections brought into the building above the ground floor level, a suitable pull box must be installed.

Overhead service conductors should be of copper, and the support bracket closest to the building must be at least 15 feet above the finished grade at the building.

Service drops may be multiconductor cables or solid conductors, either rubber covered or thermoplastic covered. In size, they must be of a current-carrying capacity that will ensure that current for loads can be conducted without a temperature rise that might be harmful to the insulation. (See the later section, Wire Sizes.) Naturally, they must have adequate mechanical strength. If the wire is of soft copper, nothing smaller than No. 8 may be used.

The service conductors in figure 4-1 allow for the operation of electrical devices rated at either 230 volts or 115 volts. A 230-volt single-phase motor (in addition to lights) can be operated on this system. If a three-phase motor is to be part of the electrical equipment of the building, 4 service conductors will be required.

Service entrance conductors are that portion between the point outside the wall, where the conductor is spliced or tapped to the service drop, or other source of supply, and the terminals of the service equipment (in fig. 4-1, the switch box). Note how the three conductors are tapped onto the outside service leads, and how the wires are led through a metal pipe into the building, where they are connected into a service switch.

At various spots throughout any wiring system, conductors must be spliced or joined. The splice must be mechanically and electrically secure without solder. Copper wire should always be soldered, or spliced with some kind of mechanical connection.

Splices, joints, and free ends of conductors must be covered with insulation equivalent to that on the conductor.

Panelboards

One big advantage of having an electrical plan is that you can install service switches, lighting panels, and convenience outlets before any wiring is installed.

The service switch is the point at which you will make the necessary connections between the service entrance conductors and the interior wiring. The copper blades of the switch, when in contact, form a continuous circuit between the outside distribution source and the inside wiring. When the blades are in the OFF position (that is, with the blades pulled open), the circuit is broken.

The knife blades should be checked for full alinement with the contacts. Where there is poor contact, there will be some loss of current-carrying capacity, and heating of the switch.

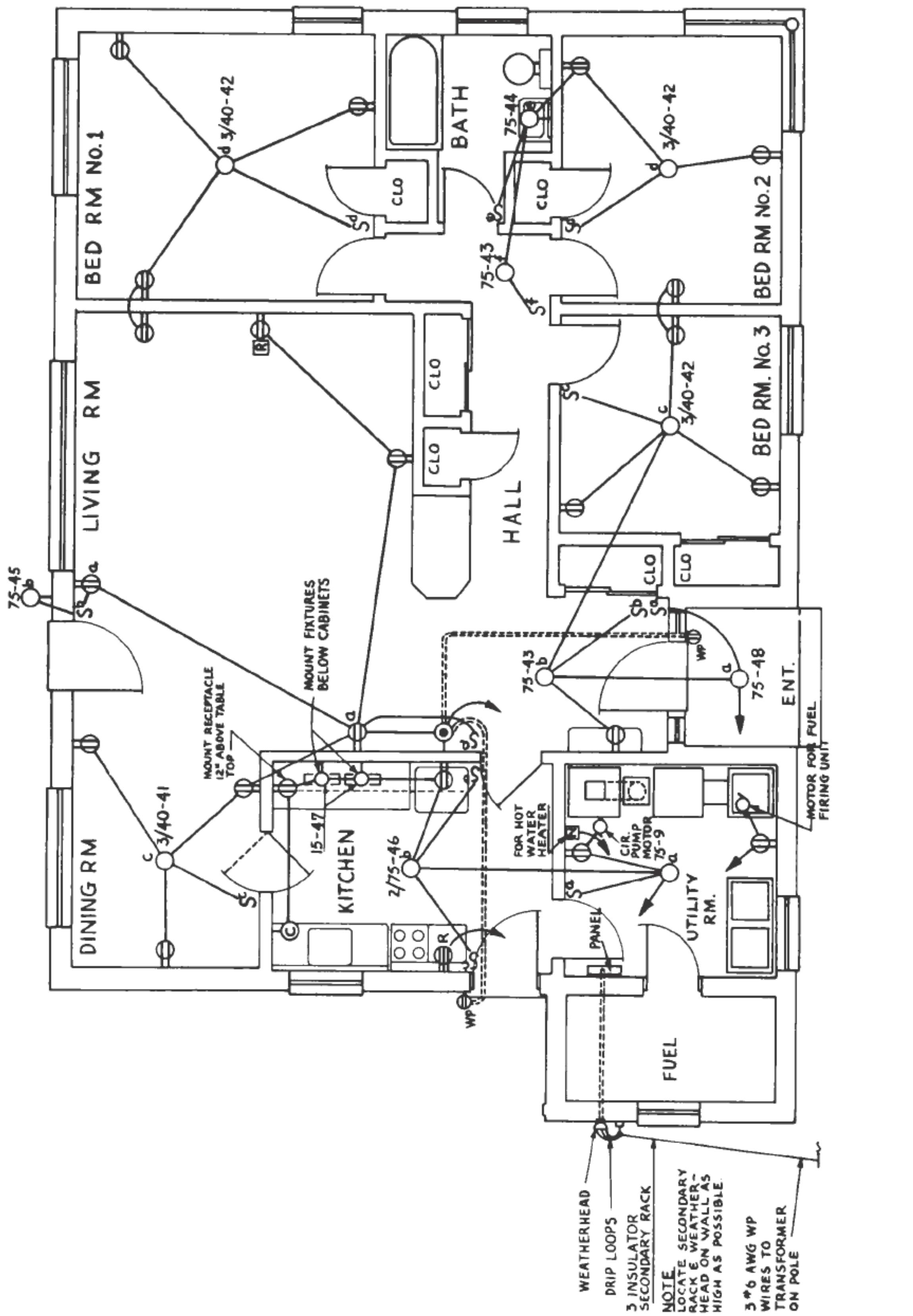


Figure 4-2.—Floor plan for an interior wiring system.

Since all incoming voltage and current must pass through this switch before any of the electrical devices in a building can be energized, you should open the switch in case of fire, or other serious emergency.

In small buildings, the lighting panelboard and service switch can be installed close to each other. Mount them securely, about 5 feet above the floor. A board fastened to the wall with lag screws or anchor bolts makes a good mounting surface; the panelboard and service switch boxes can then be mounted on this board with wood screws.

If you are working in a newly constructed building where only the framework has been set up, it will be a simple matter to arrange for a concealed installation. Fasten the box to a stud; when the plaster or wallboard is applied, the face of the box will be flush with the finished wall.

In locating panels, you must satisfy certain basic requirements: the panels must be placed where service and maintenance can easily be performed; they should not block any passage that is supposed to be free; they must not be in a place where they will be exposed to corrosive fumes, or to dampness; and they should be located as near as possible to the center of the electrical load.

The circuits controlled at the panelboard must be clearly indicated. List their numbers in order, from top to bottom, with the odd numbers on the left. Fasten a copy, protected with a plastic cover, to the inside of the panel door.

When you install a panelboard, make some provision for adding new circuits, if the need for them should arise. This is a good rule to follow in all except very small installations.

Outlet Boxes

The main purpose of an outlet box is to connect the elements of the electrical system, and to provide a convenient space for mounting devices. However, the outlet box can also help to hold the conduit in position.

Outlet boxes may be classed according to shape—square, rectangular, and eight-sided. The latter is used mostly for lighting fixtures; square and rectangular boxes are used for switches and convenience outlets.

Use a steel outlet box for all rigid conduit. The box should be at least 1 1/2 inches deep, except where job conditions require a shallower box.

Conduits protect the wires of a system most of the way, but when the wires reach a point at which a switch is to be installed, or a lighting fixture placed, the outlet box provides the protection.

The conduit, however, must enter the outlet box. This is the reason for the partially punched disks, or knockouts, that are stamped on the surface of the boxes. Be sure to remove the proper number of knockouts, so that all the conduit runs can be brought into the box. These knockout holes are threadless, so that you will have to secure the entering conduits with bushings and locknuts. Do not try to make too many connections in an outlet box; four is a safe limit for most boxes.

Every conductor running through a box is counted as one conductor, and every conductor entering and ending in the box is counted as one conductor. (A conductor that ends in an outlet box must have a support within 12 inches of the box.) Table 4-1 will help you to decide the size of outlet box required for any given number of conductors.

The distance from the finished floor to the center of the wall outlet must be at least 12 inches; a switch box mounted beside a door must be at least 48 inches above the finished floor.

Ceiling outlet boxes may be fixed directly to the ceiling, in an exposed installation. In more finished work, the installation should be concealed; in these cases, you can mount a metal bar hanger between the joists of the ceiling framework, and then secure the outlet box to this bar.

Lighting fixtures will probably be stock fixtures. However, for ceiling or wall lights in hazardous locations, you will have to take added precautions. Figure 4-3 indicates safe installations in such cases.

If the bottoms of lighting fixtures in a building are 25 feet or more above the finished floor, you will have to provide some type of lowering device, so that the fixture can be brought into reach for maintenance or bulb replacement. This lowering device must allow for disconnecting the fixture from the electrical circuit, lowering it, raising it again to operating position, and reconnecting it to the circuit.

Table 4-1.—Deep Boxes: Sizes Required for Given Number of Conductors.

Box Dimensions (Inches)	Maximum no. of conductors			
	#14	#12	#10	#8
1 1/2 x 3 1/4 (8-sided)	5	5	4	0
1 1/2 x 4 (8-sided)	8	7	6	5
1 1/4 x 4 (square)	9	7	6	4
1 1/2 x 4 (square)	11	9	7	5
2 1/8 x 1 3/4 x 2 3/4	5	4	4	-
2 1/2 x 1 3/4 x 2 3/4	6	6	5	-
3 x 1 3/4 x 2 3/4	7	7	6	8

Pull Boxes or Junction Boxes

Pull boxes can be a great convenience in any installation. They can be used instead of conduit elbows; not only are they less expensive, but they also serve the purpose better when a number of turns occur in the conduit. A good rule is to use a pull box when a conduit run contains more than three right-angle bends.

In most cases, standard pull boxes can be used, but there will be occasions when a box must be built to fit particular job conditions. For a pull box installed in a 1 1/4 inch conduit run, the box length must be at least 8 times the conduit diameter. A pull box with a volume of more than 100 cu in. must be reinforced.

Make sure that each box is easy to reach. Use machine screws to fasten down the covers. If a box is intended for outside installation, it should be galvanized; an enamel finish is adequate for a box used inside.

Junction boxes are similar to pull boxes, but (as their name implies) they are used as a place where you can train and arrange conductors, splice them, or tap off a branch circuit. Figure 4-4 illustrates conduit runs passing through junction boxes and feeding convenience outlets on a workbench.

The cover plate on one junction box, in the bottom center of the illustration, has been removed, and you can see the way in which the conduit enters the box, and the spliced wires within. Notice that the cover of the outlet box, upon which the man is working, differs from the plain metal cover used on junction boxes.

Conduits

The conduits in which you install the wires of an interior wiring system may be either the rigid conduit type, or the thin wall (electric metallic tubing) type. The size of the conduit used will depend upon the number and size of the wires to be installed.

Conduit SIZE is indicated in terms of the inside diameter. The range is from 1/2 to 6 inches. Rigid conduit of a given inside diameter will hold the same number of wires as thin wall of the same inside diameter, but there will be a decided difference in wall thickness. Both types will come in 10-foot lengths, with a coating to protect them against corrosion. The thin wall has a zinc coating, but rigid conduit is coated inside and out with a coating of zinc or of black enamel. Also, the rigid conduit type is always threaded at both ends, and has a coupling included at one end only.

RIGID CONDUIT is suitable for all atmospheric conditions, for all types of occupancy, and for both exposed and concealed work. If the conduit is to be installed in a damp location, or where walls are to be washed frequently, the whole conduit system (and this includes boxes and fittings) must be made watertight. Avoid using conduit that has been stored in a place exposed to the weather.

Since the conduit comes in 10-foot lengths, you will almost always have to do some CUTTING in order to meet the needs of your installation. A hacksaw is best for this; and if possible, you should have the conduit in a vise, to hold it steady during the cutting operation.

Always make your cut at right angles to the side of the pipe. Use long, steady strokes at normal rate of speed. Notice that the blade teeth of the hacksaw point forward; this means that the forward stroke is the one that does the cutting, and therefore it is the only stroke upon which you must use pressure.

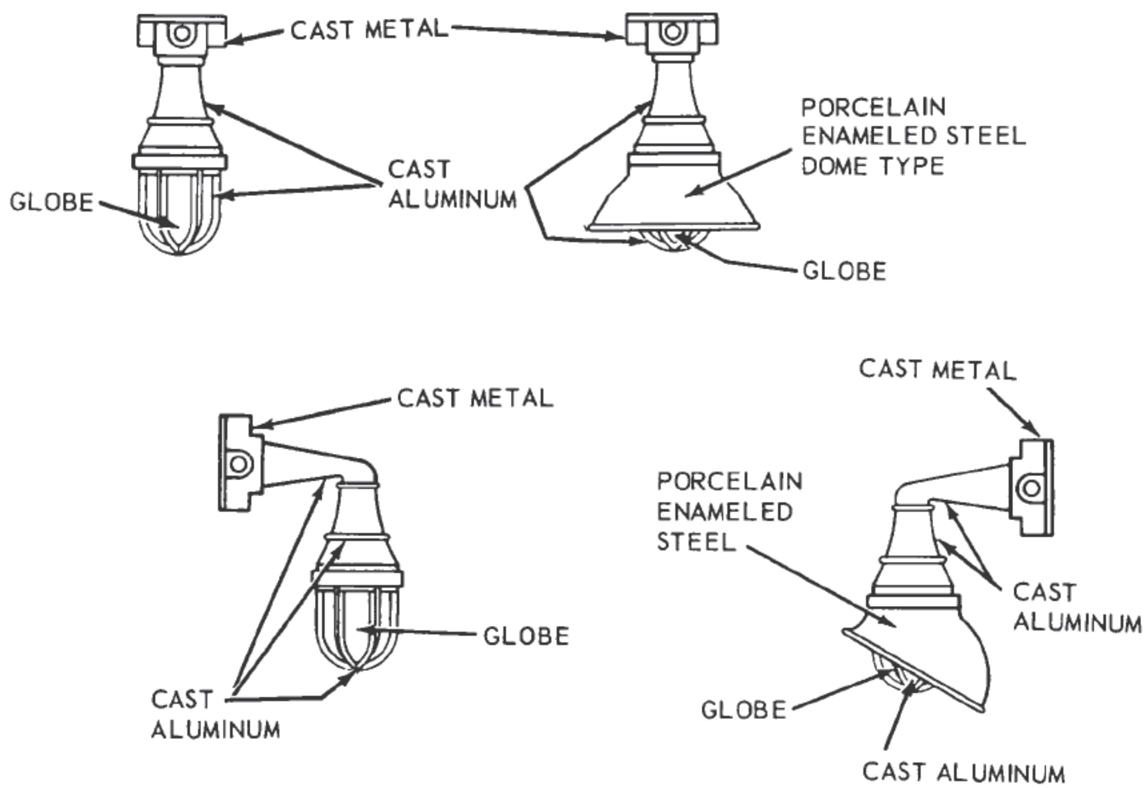


Figure 4-3.—Lighting fixtures for hazardous locations.

If you have to use a pipe cutter, you will probably find that a burr remains on the inside of the conduit. For this reason, a hacksaw is always preferable.

However, if you must use a pipe cutter, use cutting oil, and be careful to get the cutter into the right position on the conduit. First fasten the conduit in a vise, then slide the cutter along. The cutter wheel marks the place where the cut is to be made. Tighten the cutter handle until the cutter bites into the conduit. As you continue the cutting operation, tighten the handle by one-quarter turn each time the cutter completes one full turn around the conduit.

REAMING the conduit will be necessary whenever a cut has been made. This reaming is done to remove the burr, or sharp and ragged edge, left inside the conduit. You can see that this ragged surface might damage the protective cover, or even the insulation, of the conductors that will be pulled into the conduit.

Use a brace and reamer to smooth down these sharp edges. In some cases, the burr can be smoothed off with a half-round or rat-tail file.

THREADING the newly cut end of a conduit is a necessary step, if threaded connections are to be used. All dies for conduits should cut running threads. On a small-sized conduit, you can use a die that cuts a thread with every turn. On a large-sized conduit, use a ratchet-type stock and die.

First secure the conduit in a vise, with the end to be threaded projecting about 8 inches beyond the workbench. Slide the stock over the conduit until the conduit contacts the die. Exert a forward pressure on the stock handle, until the die begins to cut; after this, no pressure is needed, as the die will draw itself up the conduit, as the handle is moved backward and forward in a short arc. Figure 4-5 shows a ratchet-type threader, and the vise which should be used.

In using this tool, make sure that the handle of the stock is kept at right angles to the conduit. Apply cutting oil to the thread, die, and conduit every two or three turns. When the threads have been cut, check the conduit before you install it, to make sure that no dirt or dust remains in it.

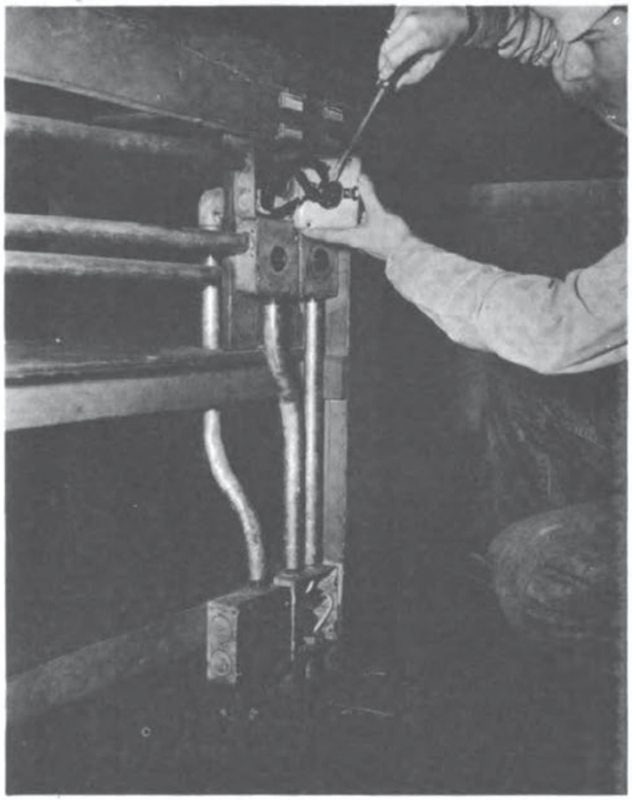


Figure 4-4.—Junction and outlet boxes.

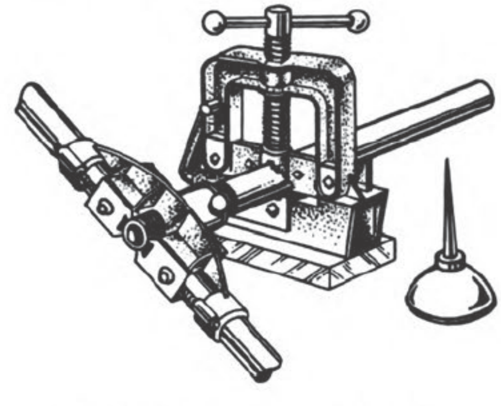


Figure 4-5.—Threading a conduit with a ratchet-type stock and die.

Running threads (where an entire coupling can be screwed on the conduit) are not satisfactory for grounding purposes, because they so often result in a loose joint, and poor conductivity.

Threadless couplings and connectors can be used, but they must be tight. If they are in a part of the system which will be installed in a wet place, or in fill or concrete, make sure that they are watertight as well as electrically tight.

The run of a conduit should be as direct and straight as possible, but in every installation there will be spots where BENDING the conduit will be necessary. Indeed, for right-angle bends in exposed work, it is better to bend the conduit than to use standard elbows.

For field bends—that is, bends that are made at the location where the conduit is being installed—the radius of the bend for rubber-covered or braid-covered conductors must be 6 times the inside diameter of the conduit; for lead-covered conductors, the bending radius should be 10 times the internal diameter.

Some type of hickey for bending conduits by hand will probably be available to you at any base where you are working. They are useful on conduits up to and including the 3/4 inch size, and are especially good when bends must be made in awkward positions. A vise, or a hand tube bender, like the one shown in figure 4-6, is also suitable for bending thin wall conduits. Large-sized conduits should be bent with jackscrews, or with a hydraulic bender. Whatever method you use for making a bend, take care that the conduit is not damaged, nor the inside diameter reduced.

If possible, lay out the bend in chalk, on the floor; this provides a crude diagram that you can use for comparison, as you form the bends.

Conduit FITTINGS are made to meet almost every requirement and condition of an electrical installation. The manufacturers of these fittings use the same type names for identification. Type SE represents service entrance fittings; type C represents through fittings; type L represents turn fittings; and type T represents through fittings with a 90-degree takeoff. For exposed work, special fittings (called CONDULETS, UNILETS, or similar trade names) make the best appearance. These fittings are usually L-shaped or T-shaped.

On rigid conduits, outdoor fittings should have a rubber gasket between fitting and cover. Special fittings are made to resist the effect of corrosive fumes.

Although a single coupling is provided with each 10-foot length of conduit, elbows must be ordered as separate items. For joining lengths

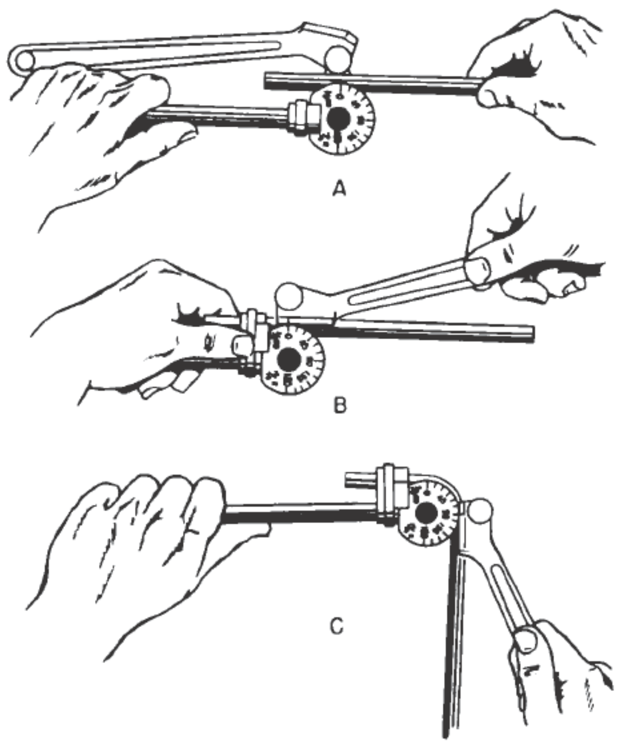


Figure 4-6.—Tube bender, hand type.

of conduits, threaded conduit unions are preferable to running threads; their use permits opening the conduit at almost any point.

On exposed conduit runs, fittings can sometimes be substituted for junctions and pull boxes. Their smaller size results in a better appearance than would a pull box.

Probably the fitting which you will use most frequently is the L-type fitting. This fitting is especially useful if you must make a connection between a conduit attached to a wall and one that extends through the wall. An opening in the L fitting makes it fairly easy to fish the wires (installed in the conduits) through the 90-degree bend.

Conduits must be INSTALLED either parallel to or at right angles to building walls. The straighter the run, the easier it will be to install the conductors. When there are to be parallel, adjacent runs, do them at the same time, rather than installing one line before you start another.

Where a conduit is to be installed in a building with concrete floors, the conduit should be in place before the concrete is poured. In other types of buildings, the actual running of the conduits may be one of the last steps in the installing of the interior wiring. The floor plan (fig. 4-2) has provided you with the necessary information about the location of outlets, and these are often installed before the actual running of the conduit. The service switch and panels will also have been installed. The conduit is then run to make the indicated connections.

Figure 4-7 indicates how to install a conduit between the panelboard and a ceiling light.

Starting at the panelboard, bring the conduit upward along the wall, to a distance of about 12 inches below the ceiling. At this point, make a right-angle bend, and carry the conduit along the wall, and parallel to the ceiling. Run the conduit through the partition (if any), and continue parallel to the ceiling until you are at a point in line with the ceiling outlet. Here, make another right-angle bend, and carry the conduit upward to the ceiling line. Finish the run by carrying the conduit along the ceiling to the outlet.

Be careful not to place the bends too close together, since that will make the work of installing the conductors much more difficult.

FASTENING the conduit to walls or ceilings is an important step, since the conduit run must be secure. The method of fastening depends upon the composition of the surface against which the conduit rests. Cable clips, pipe straps (either one- or two-hole), and hangers are the usual forms of support.

When conduits are to be fastened to brick or masonry surfaces, drill the necessary holes with a star drill (or, better, an electric drill), and then fasten the conduit to the surface with metal inserts, metal expansion screws, or toggle bolts. To fasten conduits to a steel surface, use bolts or machine screws. On tile or other hollow material, use toggle bolts. On wood surfaces, use lag screws or wood screws.

USE OF THIN-WALLED CONDUIT should be confined to dry locations, since any exposure to the elements causes rust. Further, it cannot be subjected to corrosive fumes, nor should it be used where it may suffer mechanical injury during or after installation.

The same precautions, about relative size of bending radius and inside diameter, and about kinking the pipe or otherwise reducing inside diameter, apply to metallic tubing as to rigid conduit.

Since the walls of metallic tubing are too thin for threading, the fittings used with this tubing are chiefly of the threadless type, although rigid conduit fittings can be used with adapters.

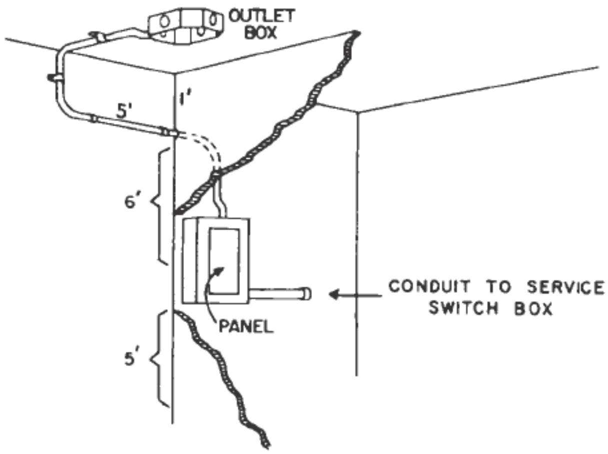


Figure 4-7.—Running a conduit.

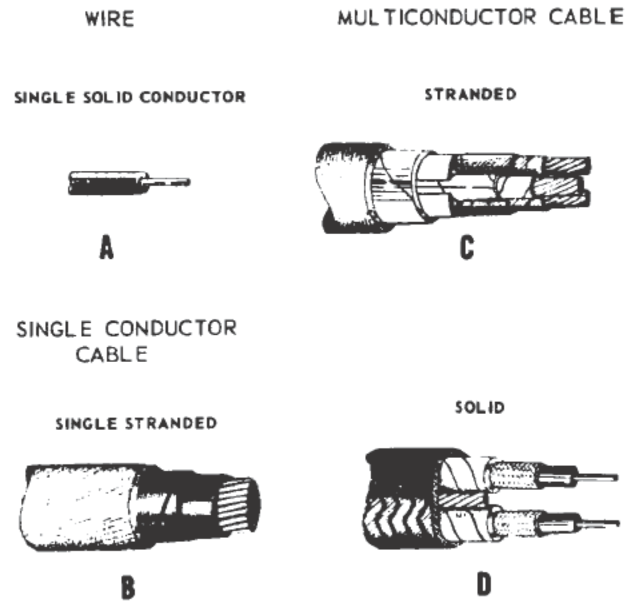


Figure 4-8.—Wires and cables.

It is possible, also, to get pipe couplings and box connectors, although no couplings are furnished with each 10-foot length.

This tubing can be cut with a hacksaw, or with special types of cutters. Reaming is necessary to remove sharp edges before the conductors are installed. The number of conductors that may be installed is the same as the number allowed for rigid conduit of the same diameter.

At points where you have to connect a thin walled conduit with a run of rigid conduit, you should use an adapter.

CONDUCTORS

The conductors in the wiring system may be either single wire or cable. A wire is always a single, solid conductor. A cable may be single stranded—that is, it may be composed of a group of wires that are not insulated from each other. Again, it may be composed of solid conductors insulated from each other; or it may be of stranded conductors, each group insulated from the other.

The advantage of using stranded conductors is that they have greater flexibility than the solid conductors. This makes it possible to carry conductors through fairly sharp curves, where a solid conductor would present a real problem.

Figure 4-8 illustrates the differences between wire, single-conductor cable, and multi-conductor cable.

Wire Sizes

The size of a conductor is measured by the diameter of its cross section. For a solid conductor, the diameter represents the widest distance across the cross section; for a stranded conductor, this is equally true, although it may be a little difficult, at times, to determine the greatest overall width.

Most conductors have diameters so small that they are measured in small decimal fractions of one inch. To simplify computations involving wire diameters, the term MIL has been established as the measurement. A mil equals 0.001 inch; having a single term to express this decimal value is a decided advantage. Sometimes it is desirable to express size of conductor by the area of its cross section. Since the area of the cross section of a wire is obtained by squaring its diameter in mils, this measurement is a convenient one. Figure 4-9 illustrates the measurement of solid and of stranded conductors.

Even though wires are made by a number of different manufacturers, by agreement they all conform to a single standard of measurement. This is the American Wire Gage standard (AWG), in which size of wire is indicated by a number instead of by a diameter expressed in fractional inches or in mils.

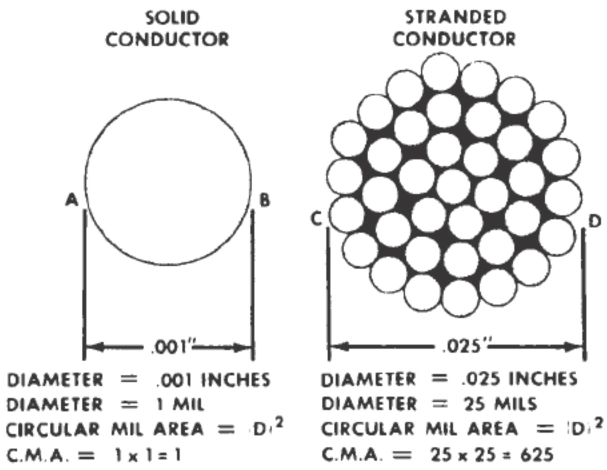


Figure 4-9.—Measuring solid and stranded conductors.

Table 4-2 shows the AWG information for those wire sizes which you are most likely to use, especially in an inside wiring job. The smallest wire in the AWG standard is No. 40, but you will have little need for information about anything smaller than No. 18, so the table has been cut off at that point.

The wire size No. 0000 (usually referred to as 4/0) is the largest size in the AWG standard, but not the largest size available. For wires larger than 4/0, the circular mil, which is the cross-section area, is always used to denote size.

For each specific size of wire given in the table, you can read the diameter in mils, the area in circular mils, and the current-carrying capacity of the particular size of wire. Remember, the smaller the wire, the larger the number by which it is identified.

The figures on resistance (ohms per 1000 feet of conductor, at room temperature) represent resistance to direct current. Conversion factors make it possible to obtain the resistance to alternating current. These conversion factors are only slightly more than unity; that is, for a given wire size, the factor might be as small as 1.005. Only when you are dealing with large conductors, with size denoted as 250,000 circular mils or higher, will the conversion factor be as much as 1.1 or 1.2 representing an increased resistance of one-tenth or two-tenths more than the resistance to direct current.

For interior wiring, you will probably use No. 14 oftener than any other size. Fixture wires and cords may not be of smaller sizes than No. 16 or No. 18. These sizes are considered as protected by 15-amp overcurrent devices.

Smaller wires than No. 18 (as small as No. 40, in fact) are used for the coils on some motors, and on instruments, measuring devices, and so forth. Such wires, however, are provided as part of the component.

When a number of conductors must be carried in a conduit, the conduit diameter must be large enough to accommodate the wires. This is especially important where the length of the conduit run is more than 50 feet, or where a number of bends must be made in the conduit. Table 4-3 shows the recommended diameter of the conduit to be used for from one to nine conductors, from size No. 18 to size No. 4/0. The conductors may be either rubber or thermoplastic covered.

If you are not sure of the size of any wire, you can easily determine it by the use of a tool known as a wire gage (see fig. 4-10). This device consists of a disk with notches of different sizes punched along its edge. The figure marked alongside each notch indicates the AWG number of the wire that will fit into that notch.

To measure a wire or a cable, strip off the insulation, and insert the bare wire into the notches until you find one into which it fits. The fit must be at the edge of the disk, and not in the hole at the inner edge of the notch.

Types of Insulation

Conductors must be covered with an insulating material, to prevent the current from being diverted away from the path planned for it—that is, the path from the power source to the fixture or equipment to be served.

You know that some substances or materials are much better than others for CONDUCTING electricity, and that these are the materials that are chosen for use as conductors. The materials that are poor conductors are therefore used as insulators, to prevent electrical leakage.

Some of the best insulators are: dry air, glass, mica, rubber, asbestos, and bakelite. Remember, however, that these materials will not positively and completely stop the transfer of electric current—rather, they are materials

Table 4-2.—American Wire Gage Table: Properties of Copper Conductors.

A.W.G	Diameter in mils (d)	Area in circular-mils (d^2)	Ohms per 1,000 feet at 20° C. or 68° F.
1	2	3	4
0000	460.00	211,600	0.04893
000	409.64	167,810	.06170
00	364.80	133,080	.07780
0	324.86	105,530	.09811
1	289.30	83,694	.1237
2	257.63	66,373	.1560
3	229.42	52,634	.1967
4	204.31	41,742	.2480
6	162.02	26,250	.3944
8	129.49	16,509	.6271
10	101.89	10,381	.9972
12	80.808	6,529.9	1.586
14	64.084	4,106.8	2.521
16	50.820	2,582.9	4.009
18	40.303	1,624.3	6.374

that have such a high resistance that they are extremely poor conductors.

Another point to remember is that insulation has its voltage rating, as conductors do. Therefore, it would be dangerous to use an insulating material meant for 110 volts on a conductor that is rated to carry 220 volts. (Building wire is rated at 600 volts by underwriters.)

In interior wiring especially, where limited space may require that the wires be placed very close to each other, proper insulation is a most important feature. Otherwise you may have short circuits, where the current forms an independent path by jumping from one conductor to another; or you may have grounding, where the current jumps from the conductor to a nearby radiator, or other metal object.

Rubber is probably the insulation most commonly used. The higher the voltage through the conductor, the thicker the rubber should be. However, chemical reaction between copper and rubber makes the latter soft and gummy; a thin coating of tin is used, therefore, between a solid conductor and its insulation, and a winding of soft, cotton thread is used between a stranded conductor and its insulation. Figure 4-11 indicates how these protecting materials should be applied.

Asbestos-covered and thermoplastic-covered conductors are also used in spaces where prevailing temperatures or other conditions make rubber-covered conductors undesirable.

For example, insulation must be capable of withstanding the heat that is generated as current flows through the conductor. Rubber is a satisfactory insulating material as long as temperatures do not climb too high; this is one

Table 4-3.—Number of Conductors in Conduit or Tubing.

Size of conductor (AWG)	Number of conductors in one conduit or tubing of specified diameter								
	1	2	3	4	5	6	7	8	9
18	1/2	1/2	1/2	1/2	1/2	1/2	1/2	3/4	3/4
16	1/2	1/2	1/2	1/2	1/2	1/2	3/4	3/4	3/4
14	1/2	1/2	1/2	1/2	3/4	3/4	1	1	1
12	1/2	1/2	1/2	3/4	3/4	1	1	1	1 1/4
10	1/2	3/4	3/4	3/4	1	1	1	1 1/4	1 1/4
8	1/2	3/4	3/4	1	1 1/4	1 1/4	1 1/4	1 1/2	1 1/2
6	1/2	1	1	1 1/4	1 1/2	1 1/2	2	2	2
4	1/2	1 1/4	1 1/4	1 1/2	1 1/2	2	2	2	2 1/2
2	3/4	1 1/4	1 1/4	2	2	2	2 1/2	2 1/2	2 1/2
0	1	1 1/2	2	2	2 1/2	2 1/2	3	3	3
00	1	2	2	2 1/2	2 1/2	3	3	3	3 1/2
000	1	2	2	2 1/2	3	3	3	3 1/2	3 1/2
0000	1 1/4	2	2 1/2	3	3	3	3 1/2	3 1/2	4

of the reasons why it is used so much for interior wiring.

In power plant switchboards, where high operating temperatures are the rule, varnished cambric is used in place of rubber. It is also used on generator and transformer leads, because it is not affected by oil or grease. Felted asbestos has an even greater resistance to heat, but breaks down when exposed to dampness, and so changes from an insulator to a conductor. However, an outer coating of varnished cambric will give the asbestos insulation the necessary protection from moisture.

Thermoplastic conductors are used on wires in spaces where above-normal temperatures are maintained and in spaces where the insulation must be oil resistant.

When cables must carry an extremely high voltage, insulation of rubber, asbestos, or varnished cambric is likely to break down. Therefore, cables of the proper voltage rating should be selected. High-voltage conductors are usually wound first with a metallic tape, and then with a thin paper cover soaked in a heavy oil mixture and applied in the form of tape. The purpose of the metallic tape is to reduce the reaction between the rubber and the oil-soaked paper insulation.

For telephone switchboards, where the number of talking circuits necessary means an equal number of pairs of wires in the cable, each conductor is wound with silk and cotton threads. The silk is wound in one direction, the cotton in the reverse direction, and the threads are then soaked with a special wax compound. Use of silk and cotton keep the size of the cable small enough for easy handling.

In the following chapter, Chapter 5 Meters and Controls, you will learn something about the electromagnetic coils that are used in meters and relays. It might be well to describe how these coils are insulated, while we are on the subject of conductor insulation.

These electromagnetic coils are formed of a large number of turns of magnetic wire. Since the overall size of a coil must be held to a minimum, the wire is insulated by a thin coating of enamel.

This enamel coating is adequate, because the wires in these devices carry only a very

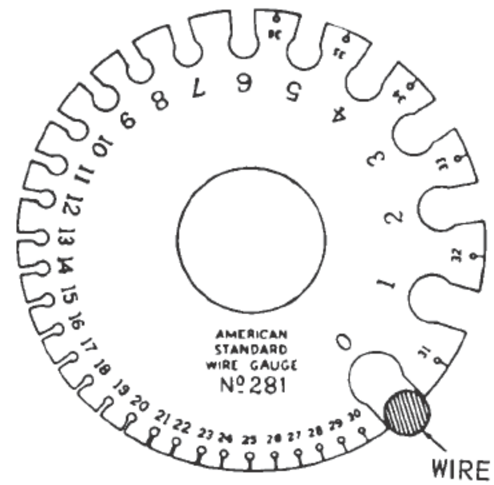
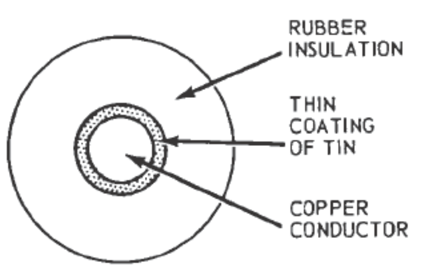


Figure 4-10.—Gage being used to determine wire size.

small current. In working with an enameled wire, however, you must always be careful not to scratch or nick the enamel. A very slight damage to this coating could result in a short circuit.

RUBBER INSULATED SOLID CONDUCTOR



RUBBER INSULATED STRANDED CONDUCTOR

Figure 4-11.—Separation of rubber insulation from a copper conductor.

Neutral Wire

In a 3-wire system, such as that illustrated in figure 4-1, one of the wires from the distribution pole will be the neutral wire. This may be the middle wire, or it may be the top wire; but in any system, the neutral wire will always be in the same position.

As you make your connections at the house knobs, to carry the wires through the conduit, be sure to use white or gray wire for this neutral wire, and black and red (or two black wires) for the hot wires.

You want to understand the purpose of the neutral wire. Remember, the path of electricity is always from source to source. As the current follows this path through conductors, it energizes the fixtures and the equipment that have been connected into the line.

You can understand, therefore, how necessary it is to ensure voltage return. In general the fixtures can be thought of as resistance in series in the hot wires, one of which is carrying the voltage to the load, and the other carrying the voltage back to the source. The neutral wire serves the purpose of ensuring voltage return in an UNBALANCED circuit.

In case of unequal loading, current flows through the neutral wire, either from the power source or back to it, according to whether the load is heavier on one hot wire or on the other. In a building wiring system, it is safest to have the neutral wire the same cross-sectional size as the live wires. In power plants, the neutral wire may be as small as one-fifth the cross section of the live wires, as you will see if you read Chapter 6, Power Distribution.

The return line, or neutral wire, should never be broken by a switch; all necessary switches must be placed in a live wire. If you will look back at figure 3-9, you can see how the neutral wire there has been kept unbroken. It passes unbroken through the service switch box; it splits in two directions (which is not the same thing as a break made by an open switch), one wire being grounded to a water pipe—the best method of grounding. The other wire passes to the NEUTRAL bar of the panelboard, and from there runs unbroken to each fixture in each branch circuit. All switches are in the live wires.

Properly installed, the neutral wire is always at ground potential. The live wires, however, are never at ground or zero potential unless the switches are opened; and they are never safe to work on UNLESS they are at ground potential.

Cables

In most interior wiring systems, the wires must be carried through a conduit. There are only a few exceptions to this rule; and since they are so few, we may as well clear them out of the way before we go on to the usual type of installation.

In temporary prefabricated buildings, such as quonset huts, it would not be practical to install conduits. This would make dismantling and re-erection of the buildings a longer and more expensive job than would be necessary. For such buildings, therefore, it is satisfactory to use a nonmetallic sheathed cable, or an armored cable. These two types of cable take their names from the type of protective covering which is given to the wires.

NONMETALLIC SHEATHED CABLE, usually known by its trade name of Romex, is rubber-insulated wire which is given further protection by a braid covering that has a high degree of resistance to moisture, flame, and mechanical injury.

ARMORED CABLE, or BX, is insulated wire with a flexible metal cover as protection. The flexibility of this protective cover makes it easy to bend; another advantage is that it can be run uninterruptedly from outlet box to outlet box, where rigid conduit would require coupling at least every 10 feet. However, the armored cable cannot be threaded, and therefore special types of clamp connectors must be used.

A lighting system for a quonset hut would normally consist of a lighting circuit, with Romex as the conductor, extending lengthwise along the top of the hut, and with the switch installed at the doorway. Figure 4-12 illustrates how the lights should be installed. Although not visible in the illustration, there are two wood screws that hold the bakelite lampholder to the ceiling.

FLEXIBLE CORDS may be used only under suitable conditions. Chiefly, this use will be for portable lamps and appliances; they must never be used as a substitute for the fixed wiring of a structure.

Even when the conditions of use and location permit the use of flexible cord, there are still several precautions which must be taken. For example, flexible cord can be used only as a continuous length; it must never be spliced or tapped. Never use it where it must be carried through doors or windows, or through holes in walls, ceilings, or floors. Do not use it where

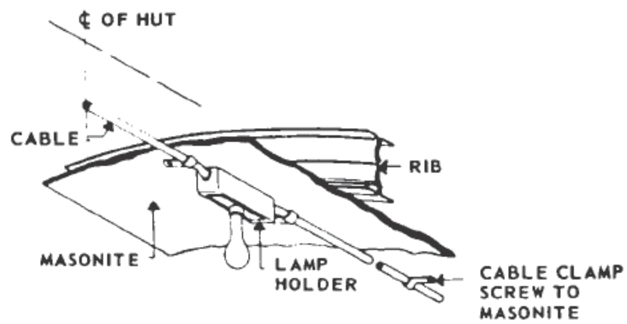


Figure 4-12.—Quonset hut lighting installation, with Romex as the conductor.

the wiring must be attached to the building surfaces. Above all, never use flexible cord for any wiring which will be concealed behind walls or ceilings, or under floors.

Even at advanced bases, you should make sure that your installation is in accordance with the requirements of the NATIONAL ELECTRIC CODE. These regulations and requirements have been established in the interests of safety, and should not be neglected nor disregarded merely because there is no likelihood of an inspection by the regulating agency.

Installing the Wires

When the service switch, panelboards, and various outlets have been located, and the conduit system is in place, you are ready to install the wires.

The number of wires to be installed in each conduit depends upon the electrical plan. However, more than 9 wires should never be installed in a conduit, regardless of the space available. The plan will also indicate the neutral and the hot wires. Remember that fixture and convenience outlets are tied between a neutral and a hot wire, with the switch placed in the hot wire. Any solid color except green (usually red or black) is used for live wires; the neutral wire is white, or has some identifying marks. The green is for equipment grounds only. The hot wires and the neutral wire enter the fixture or the outlet boxes, but only the live wires are brought into the switch boxes.

The wires are pulled through the conduit with a narrow steel tape, fitted with a hook at one end. These tapes are known as fish tapes. Start this tape through the conduit at the outlet, and keep feeding it through until the hooked

end comes out at the panel or other outlet. The wires that are to be installed in the conduit are tied to the hooked end, and the tape is then drawn back through the conduit, pulling the wires with it.

If possible, station a man at the point where the wires enter the conduit run, and have him see that the wires feed in without kinks or twists. Have another man to watch and push the wire from outlet to outlet.

Once the wires have been installed throughout the conduit system, connect them to the fixtures, convenience outlets, and switches. Any necessary splicing must be completed at the same time. In splicing, remember that white wires are connected to white, and the other colored wires to matching colors.

Snap or toggle switches are generally installed in rectangular boxes. The switch is fastened to the box, and the switch plate is screwed to the switch body. The wire connections are secured to the screws. The hot wire is fastened to the brass screws on the side of the receptacle, and the white wire is fastened to the silver screws. In using screws as terminal points, always be careful to twist the wires in the same direction in which the screw tightens, to prevent accidental loosening of the connections.

In any spot where open wiring is permissible, make sure that it does not come into contact with grounded pipes or with equipment. See that it is supported properly, and that there is no unnecessary sag between points of support. Figure 4-13 indicates how wiring may be protected by running boards. Where the cable runs at right angles to floor studs, use guard strips. Exposed runs, in basements and attics, can be protected by carrying the wire alongside a rafter or stud. If the wire must run at an angle to the timbers, carry it through bored holes.

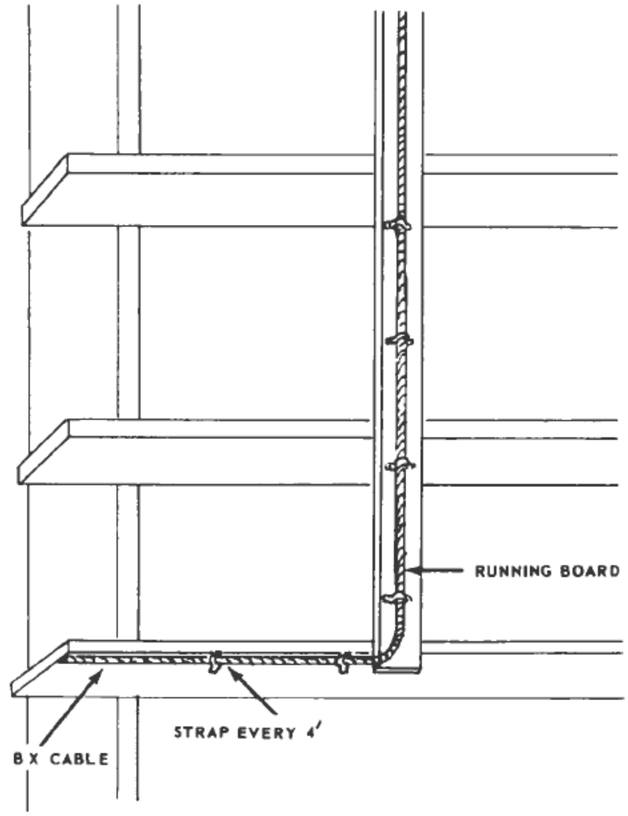


Figure 4-13.—Wires protected by running boards.

When the interior wiring system has been completely installed, make a general overall check to see that it is as safe as possible. Look to see that supply circuits are grounded, preferably to a water pipe system, on the supply side of the service switches. Make sure that grounding wire is protected against any mechanical injury by conduit or other type of enclosure. Make sure that ground connections are tight.

Check the fixed electrical equipment, to make sure that motor frames, switchboards, conduits, and metal lamp sockets are properly grounded. See that the exposed noncurrent-carrying parts of portable equipment are grounded if the equipment is being used with X-ray apparatus, or in hazardous locations, or where unusual dampness may occur.

Flexible cord on portable equipment must be free from any mechanical strain. It should be held to as short a length as possible, and kept away from plumbing or other well-grounded objects. Make sure that all portable extension cords have a nonconducting plug and outer socket shell.

Motor Branch Circuits

The elements that make up a motor branch circuit are: circuit conductors, overcurrent protection, disconnecting means, controller, and motor running protection. Circuit conductors are the wires from the panelboard to the motor. Overcurrent protective devices protect the

motor, controls, and wires against such overloads as are caused only by grounds or shorts. The disconnecting means isolates the motor and its controls when adjustment, maintenance, or repair work must be done. The controller starts, stops, and reverses the motor. The motor running overcurrent protection protects the motor, controls, and wires against damage from overloads NOT due to shorts or grounds.

CIRCUIT CONDUCTORS may be feeding current to a motor with fractional horsepower, or with horsepower in the hundreds, but the amperages for feeder circuits will be in accordance with the data in the following table, and not with the amperage stamped on the nameplate of the individual motors. Nameplate amperage, however, will be the guide when you install overcurrent devices to protect motors against overload.

In general, wires to a motor must have a current-carrying capacity that is higher than the full load current of the motor. Protective devices should be at least 125 percent of full load current.

You must ground the motor frame if the operating voltage is to exceed 150 volts. If the wires to the motor are inside armor or a metal conduit, the armor or conduit serves as a ground, but you should make sure that all joints are tight. Ground the motor frame if it is located in a place that is always damp, or if it is in a hazardous location.

Always ground a portable motor that operates at more than 50 volts. This can be done by having an extra conductor in the cord serving the motor, and having this extra conductor contact a terminal in the receptacle to which the grounded supply wire is attached.

OVERCURRENT PROTECTION devices may be fuses or circuit breakers, to protect the wires against overloads greater than starting amperage. (Starting amperage itself is greater than amperage at full speed.) These devices also protect the motor controller, which is designed to handle only the amperage consumed by the motor, and which would be damaged by a short or ground if branch circuit protection were not provided.

When fuses are used as overcurrent protection devices in motor branch circuits, a fuse must be placed in each ungrounded wire. If the device is anything other than a fuse, it must be capable of opening ALL the ungrounded wires. It may also open the grounded wire (unlike the fuse), provided that it opens ungrounded wires at the same time.

If motor branch circuits are to be tapped to a feeder at a spot not easily accessible, do not put the overcurrent device at the point of the tap. Instead, use wire of the same size as the feeder for the branch circuit wire, until you reach a point at which it will be convenient to have your overcurrent device.

A distance of less than 25 feet between tap and overcurrent device will permit the use of smaller wires than the feeder wire, if the wires have a current-carrying capacity at least one-third that of the feeder, and are protected against mechanical injury. The safest rule, however, is to use the same size wire as the feeder for the section between feeder and overcurrent device.

The DISCONNECTING MEANS for most motors will be a switch or a circuit breaker. It must be located within sight of the motor; if it is not visible from the motor, or if it is as much as 50 feet distant, it must be a type of device that can be locked in the OFF position.

In every case, the disconnect must be capable of opening all ungrounded wires at once; it may also open the grounded wire, provided that in doing so it opens all wires at the same time. The disconnecting means must disconnect both the motor and the controller, and may be put in the same case as the controller.

For portable motors, no disconnecting means other than the attachment plug is necessary. For stationary motors of 1/8 hp or less, the branch circuit overcurrent device is enough. For an installation where a single motor is all that is served by the branch circuit, a service switch within sight of the motor is suitable as a disconnecting means.

MOTOR CONTROLLERS may be manually operated, or automatic. A general-use switch or a circuit breaker can be used; however, for a portable motor of 1/4 hp or less, the attachment plug and receptacle provide all necessary control.

The controller, unless it serves also as a disconnecting means, need open only enough conductors to start and stop the motor. The device should be within sight of the motor, to prevent the danger of the motor being started while it is being worked on. The control may be directly in the motor circuit, or it may be a simple toggle switch, such as is used for lighting purposes. Controller cases, except

Table 4-4.—Full Load Current for D-C and A-C Motors of Different Horsepower, at 110 and 220 Volts.

Horsepower	110 volts	220 volts
D-C motors:		
3/4	6.6	3.3
1	8.6	4.3
1 1/2	12.6	6.3
5	40	20
10	76	38
20	148	74
50	360	180
100	---	355
A-C motors:		
3/4	10.2	5.1
1	13.0	6.5
1 1/2	18.4	9.2
5	56	28
10	100	50

those attached to portable motors, must be grounded.

The branch circuit overcurrent device can serve as controller for some types of motors—for instance, stationary motors of 1/8 hp or less that are normally left running indefinitely and that are so constructed that they will not be damaged by failure to start or by overload. Clock motors are an example.

MOTOR RUNNING OVERCURRENT PROTECTION is required to protect against overload that is not due to a short or ground in the motor branch circuit. After a motor has come to full speed, and is consuming its rated amperage, the equipment driven by the motor may require more power than the rated horsepower of the motor. To deliver this extra horsepower, the motor must consume a greater amperage than it consumes in delivering rated horsepower. This type of overload can be safely carried for short periods; but if it continues too long, the motor will be damaged.

Some type of motor running overcurrent protection (built in or otherwise) must be given to a permanently installed motor of 1 hp or more. A motor of less than 1 hp may have a built-in protective device, but if it has none, you should provide for motor running overcurrent protection.

In other words, a motor running overcurrent protection should always be provided. It may be a device built into the motor at the factory. Often, the motor controller and motor running overcurrent protection are combined in a single device. Motor running protection can also be combined with overcurrent protection in a single device, in those cases where a motor starts readily, and where starting amperage is not higher than amperage for running protection.

Switches

A switch is a manually operated means of disconnecting a circuit from the general distribution system. These devices are rated in amperes, and are capable of interrupting this rated current at its rated voltage.

A service switch must have a rating at least equal to the load carried on the system, circuit, or branch circuit that it serves. On circuits of 3 or more wires, a switch should have a 60 amp rating; on installations that consist of not more than 2-wire branch circuits, a 30-amp switch may safely be used.

Where knife switches are used, it is best to have them of an ampere rating about 25 percent higher than the expected current loads. This provides a margin for the contact wear resulting from use, and for misalinement.

The switches installed to control emergency circuits must be placed where they are conveniently accessible to the personnel authorized to use them.

FUSES AND CIRCUIT BREAKERS

A fuse is a piece of metal that will melt at a low temperature. The reason for installing fuses in an electrical system is to give protection against dangerous overload; when too much current flows, the metal fuse melts, or "blows," and the circuit opens.

All fuses are rated to carry a specified amount of current. You will usually find them marked 5 amp, 10 amp, 15 amp, 20 amp, and so on. If the current increases above that indicated by the fuse rating, the fuse will blow; an overload on a circuit will also blow the fuse, and open the circuit.

Always install a fuse that has a standard rating about one-third higher (but never more than one-half higher) than the expected current through the conductor. This prevents blowing of fuses as a result of current increases that are slight and of short duration. On the other hand, never install a fuse of considerably higher capacity. To do this would make the fuse useless, since a definite overload could exist, and the fuse would give no warning. When a fuse does blow, always determine the cause.

Almost all fuses used in inside wiring are of the link, plug, or cartridge types. The latter may have knife blade contacts, or ferrule contacts. The link fuse is an open-type fuse, and must be mounted on a switchboard, or else enclosed in a steel box. The plug fuse, like the cartridge fuse, is an enclosed type. For small ratings, a link or a fuse plug should be satisfactory.

Check the fuse blocks of cartridge fuses to see if the clips make full contact with the fuse; if they do not, replace them or use clip clamps. To test for poor contact, place the fuse in the clip, and then try to insert a strip of paper between blades (or ferrules) and clips.

Plug fuses are made in ratings up to and including 30 amp. Often they are used with adapters; the fuse screws into the adapter, and the adapter screws into the receptacle. Since you cannot fit a 30 amp fuse into a 15 amp adapter, the use of an adapter limits the possibilities of overfusing a circuit.

Like any overcurrent device, a fuse must be enclosed in a cutout box or cabinet, or else installed on a panelboard, or as a part of an approved assembly.

The plug fuses installed in the type of building used for personnel quarters should be the time delay type. Ordinarily, plug fuses and plug holders are not installed in circuits where voltage exceeds 125 volts; however, they may safely be used if the system has a grounded neutral, and if no conductor in the circuit operates at more than 150 volts.

It is doubtful if you will ever have to install, in an interior wiring system, any conductor with a larger current-carrying capacity than the rated capacity of the fuses available. If such a case should occur, you can use an arrangement of multiple cartridge fuses.

Put two (or more) fuse links inside a single cartridge. In this way, you can use two 15-amp fuse lengths to produce a 30-amp fuse, provided you have a cartridge suitable to accommodate the fuse lengths.

Take the following precautions: use fuses of the same rating, as well as of the same type and characteristics, and use as few fuses as possible.

Circuit breakers are another device used to open an overloaded circuit. They cost more than fuses, and require more space, but their action may be quicker than that of a fuse, and they have a much longer operating life. Circuit breakers, like fuses, have a time delay action that allows the circuit to carry an overload for a period of a fraction of a second to a few seconds. The percentage of overload that can be carried is indicated in the circuit breaker rating.

Circuit breakers for interior wiring are available for use on circuits with voltage from 110 to 440, and currents from 5 amp to several hundred amp. Like fuses, they are marked with standard ratings; in choosing one for use, make sure that it is not rated for a higher amount of current than the circuit can safely carry.

Some circuit breakers operate on the principle of a trigger mechanism that locks the breaker contacts, and is connected to a plunger in a solenoid. Excessive current in the circuit raises the plunger; the plunger trips the trigger; and the breaker springs open the circuit. Other circuit breakers operate on the thermocouple principle; excessive heat causes expansion of bimetallic plates, and breaks the circuit.

There are three classes of device that will open circuit breakers. They are named according to the service which they render: overload, low voltage, and reverse current devices.

An overload circuit breaker opens automatically when the load on the circuit becomes greater than that for which the circuit is safe. This load value is determined by the amount of current which the equipment and appliances connected in the circuit can safely stand. Circuit breakers are also designed to provide overload protection in case of instantaneous current, thermal overloading, and combinations of instantaneous current and thermal overload.

Low voltage current breakers open the circuit if the voltage falls below a specified value, or fails completely. This is the type of circuit breaker that is installed on some motor control panels.

Reverse current circuit breakers are designed to open at any time that the direction of current flow changes, but they will not open if current fails completely. These reverse-current circuit breakers are not part of an interior wiring system, but are the type to be installed on storage battery charging panels, and on paralleled generators, where a reversal of current flow would damage the equipment. They are also installed on motors, to prevent their acting as generators.

LAYOUT OF SECONDARY CIRCUITS

Branch circuits are the last link in the wiring system between power source and fixture. Motors usually have their own branch circuits, because of the large current they draw when starting. If there are a number of motors in use in a building, a separate power panelboard may be installed to distribute power to them. A branch circuit from a lighting panelboard may serve a number of light fixtures.

The current which each branch circuit may carry is limited by the size of wire used in the conductor. Most installations are made with No. 10, No. 12, or No. 14 wire; you should check the drawings from which you work in order to determine the proper size.

You can see exactly how branch circuits are laid out if you will turn back to figure 3-9. The panelboard is set up for six branch circuits. Nos. 1, 3, and 5 are for service in another part of the building; the actual branch circuit for No. 4 is not shown; but Nos. 2 and 6 can be traced on the diagram.

Take branch circuit No. 6, for example. One of its wires comes from the neutral bar (at the top of the panelboard), and the other from the live bar. The live wire does not connect directly with the live bar—a switch and a fuse separate the two.

The switch, of course, is to open or close the circuit. The fuse is to ensure that the circuit does not draw more than its rated current.

If you trace the hot wire and the neutral wire for the No. 6 circuit, you will see that both connect (on opposite sides) to a pair of duplex convenience outlets, and from there the wires go to three ceiling outlets. Opening the wall switch in the live wire, between convenience outlets and ceiling outlets, cuts off the ceiling lights; opening the switch up by the live bar cuts off the whole circuit.

Branch circuit No. 2 starts from the panelboard in the same manner as no. 6—that is, the neutral wire from the neutral bar, and the live wire (with switch and plug inserted) from the live bar. These wires feed four ceiling outlets, but each ceiling light is controlled by its own separate switch.

The reason for the separate switches in branch circuit No. 2 is that these lights are each in separate rooms. The floor plan in figure 4-2 illustrates this sort of hook-up. The three ceiling lights in circuit No. 6 are grouped together in one room. (You can see, now, why an interior wiring diagram of itself does not furnish all the needed information, and why a supplementary floor plan is furnished.)

The number of branch circuits that may safely be installed is determined by dividing TOTAL CONNECTED LOAD, in watts, by the maximum number of watts that can be permitted on each circuit. If the branch circuits are 110-volt carrying a 15-amp current, 1650 watts will be the maximum allowable load on each circuit. Total load divided by 1650 will show the number of branch circuits required. If your answer is a decimal figure, round it to the next highest full number; for example, a figure of 7.5 would indicate a need for 8 branch circuits.

Branch circuits for lighting may be controlled either by switches in the panels, or by local switching. The color coding of the neutral or hot wires makes it easy for you to identify them when you are installing switches or making connections.

REPAIRS

Major repairs to ELECTRICAL APPLIANCES—especially to heavy equipment—are usually best done in the shop, but there are always minor repairs and adjustments that you will be able to do on site. For example, you may have to repair worn places in protective covering or in insulation on conductors. Poor connections, causing grounds or shorts in fixtures and appliances, will need to be tightened or replaced. Worn brushes on motors, burned out heating filaments, and drop cords will sometimes need replacement.

Wiring Systems and Circuits

Although fuses and worn wires will be the most frequent source of trouble in the wiring systems and circuits (as opposed to equipment cut into the circuits), there will also be times when you will have to extend the wiring system and install branch circuits. You remember that you were advised to make provision for additional circuits in the installation of panelboards. These repairs are really in the nature of installations, and what you have already learned about interior wiring systems should give you all the knowledge you need to do these jobs.

Perhaps it would be well to say a few words here about extensions that must be carried within the plastered walls or ceilings. Underplaster extensions are made from existing outlets to new outlets. A channel is cut through the plaster, and the conduit, cable, or tubing is placed in the channel, and secured to the underlying concrete or tile. The whole installation is then plastered over.

This type of extension is made when there is no open space in wall or ceiling that would allow for fishing the wire from one outlet to another. Only small sizes of conduit or tubing is used for this type of work, and the installation must not extend beyond the floor upon which it originates.

Tools and Materials

Hand tools, materials, and equipment needed for repairs are the same as those used in installations of a system. The kit which is issued to every Construction Electrician contains the necessary tools, and the material and other equipment will be indicated on the detail plan from which you will work.

Among your tools are pliers, screwdrivers, files, and brace and bits of various sizes. A wire gage, already described in the section, Wire Sizes, is a necessary tool. Feeler gages are very convenient tools, also, although you can use a jackknife blade or thin metal strip if none is available. They consist of a number of blades, each ground to a specified thickness. With a single blade, or a combination of blades, you can find out the dimensions of any gap or clearance.

QUIZ

1. In an interior wiring system served from overhead conductors, the service drop conductors are those leading from the
   (a) distribution system to the outer wall of the building
   (b) service switchbox to the panelboard and outlet boxes
   (c) panelboard to the branch circuits
   (d) outlet boxes to the appliances
2. When underground conduits enter a building above the ground floor level, it is necessary to install a
   (a) service drop
   (b) rigid steel envelope
   (c) weather box
   (d) pull box
3. The insulation used on a free end of any conductor must be equivalent to what?
4. When the service entrance switch is in the ON position, it closes what circuit?
5. How should a panel distribution board be located with reference to the electrical load it is to service?
6. What are the two major purposes served by an outlet box?
7. Where conduits enter an outlet box, they must be provided with bushings to protect the wires from abrasion, and must be secured by
   (a) threaded unions
   (b) couplings
   (c) lock nuts
   (d) splices and knots
8. When a conduit run contains more than 3 right-angle bends, it is advisable to install a
   (a) panelboard
   (b) pull box
   (c) branch circuit
   (d) special switch
9. Which type of conduit, rigid or electrical metallic tubing, is threaded at both ends of each 10-ft length?
10. Why is it necessary to ream a conduit that has been cut with a hand saw or a pipe cutter?

11. When lead-covered conductors are to be used, the radius of the bend in a conduit should be at least
    (a) a 60-degree bend
    (b) a 90-degree bend
    (c) 6 times the inside diameter of the conduit
    (d) 10 times the inside diameter of the conduit

12. What is the purpose of the opening in an L fitting?

13. Which of the following will be best to use in fastening a conduit to a brick surface?
    (a) Machine screws
    (b) Metal inserts
    (c) Lag screws
    (d) Wood screws

14. The type of fastening used to secure a length of conduit to a wall or ceiling depends primarily upon the
    (a) length of the conduit section
    (b) number of conductors carried in the conduit
    (c) composition of the wall or ceiling
    (d) composition of the conduit

15. What is the chief advantage of using stranded conductors rather than solid conductors?

16. What are the two ways in which size of wire is indicated?

17. Is it satisfactory to use the same insulation on a 220-V line as on a 110-V line?

18. Why is insulation of special importance in an interior wiring system?

19. The primary purpose of the neutral wire is to ensure
    (a) proper grounding of the circuit
    (b) an uninterrupted path for current
    (c) voltage return in an unbalanced circuit
    (d) safety of equipment and personnel

20. In what type of building is it permissible to use Romex or BX for the interior wiring system?

21. What 4 precautions does the text specify for places where flexible cord is used?

22. In general, the number of wires to be installed in each conduit depends upon what?

23. What is the purpose of using knife switches with an amp rating 25 percent higher than expected current load?

24. What is the reason for installing fuses in an electrical wiring system?

25. What are the 3 classes of device that will open circuit breakers?

26. What type of circuit breaker is installed on paralleled generators?

27. A motor is usually given its own branch circuit because of
    (a) the large starting current required
    (b) the danger of its reversing direction and operating as a generator
    (c) the necessity for frequently cutting it into or out of the line
    (d) all of the above

28. How can you determine the maximum number of watts permitted on a circuit?

29. When is an underplaster extension allowable?

CHAPTER 5

METERS AND CONTROLS

The Construction Electrician Third Class and Second Class must know something about the types and functions of meters used in electrical maintenance, and must know how to use voltmeters, ammeters, and ohmmeters in testing circuits and equipment. As basic information, he should understand the schematic diagrams of these devices, and know how each device works, and what it measures.

In this connection, you should review *Basic Electricity*, NavPers 10086, in which a much fuller description of these devices is available. You can also learn a great deal about these meters and controls by observing the various dials and indicators mounted on the switchgear units of generating stations.

In actual practice, you should never try to repair, or even to adjust, any type of meter. Defective measuring devices should be repaired only by men specially trained in the repair of these instruments. Normally, a defective measuring device will be returned to the manufacturer or to a designated naval activity. In some Seabee units, however, selected Construction Electricians have been given training in the repair of electrical instruments; in these units, electrical measuring devices may be repaired by these specially trained men.

Although you will not repair electrical measuring devices, you should be familiar with their functions and how to handle these devices with the proper degree of care. This chapter discusses these matters.

PRINCIPLES OF ELECTRICAL MEASUREMENT

Practically all measuring instruments contain a delicate meter movement that should be so connected as to ensure that only a small value of current will flow through it.

For a-c switchboard instruments, this necessary reduction in current value is accomplished through the use of instrument transformers, mounted on the switchboard. These transformers are described in the following chapter, in the section, Switchboard and Distribution Panels.

However, for small portable instruments, and for those used in the repair shop, it is generally necessary to cut down the value of current passing through the meter movement by the use of shunts or resistors. Shunts are used for measuring heavy CURRENTS; series resistors are used for measuring high VOLTAGES.

You might call these shunts and resistors necessary accessories to voltmeters and ammeters. Other devices that are similarly accessories are rectifiers (used to convert a-c current to d-c) and thermocouples. These last two devices are described in later sections in this chapter.

Many authorities consider that if a man understands the basic movement of a galvanometer, he will have little trouble in understanding almost any type of meter. A simplified diagram of a galvanometer (which is a stationary-magnet moving-coil type of instrument) is shown in figure 5-1. In this instrument, the coil is suspended by means of narrow metal ribbons which are under tension. (In other instruments, the moving coil of the galvanometer is shaft mounted, in jewel bearings.)

This instrument is used to indicate very small amounts of voltage or of current, as in bridge circuits.

The stationary magnet in the galvanometer is horseshoe-shaped, with the opposing poles brought close together. The fixed iron core between its poles (inside the moving coil) helps also to concentrate the magnetic field. The movable coil is suspended between the poles of the magnet, by flat ribbons of phosphor bronze. These ribbons provide a path for the current between the circuit under test and the meter coil, and they also provide the restoring force for the coil, so that when current is interrupted, the coil returns to its original position.

When voltage is applied, the coil turns, and consequently turns the ribbons, which twist through an angle proportional to the applied

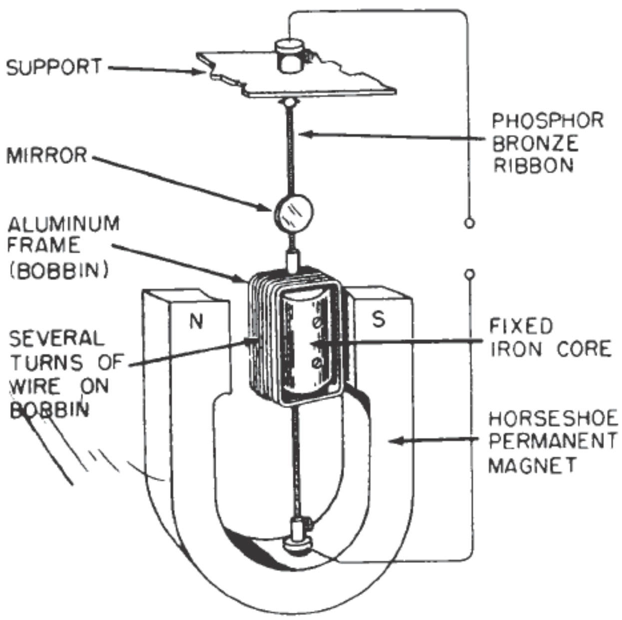


Figure 5-1.—Diagram of a galvanometer.

voltage. The tension on the phosphor bronze ribbons furnishes a mechanical resistance to the movement of the energized coil.

In the illustration, a mirror is mounted on the metal ribbons. In most meters, a pointer, instead of mirror, is attached to the coil. The used of the mirror and a beam of light gives an extremely accurate result, since it eliminates any problem of coil balance, such as you have with the attached pointer.

However, the use of a pointer has a great advantage, in that it provides a greater degree of simplicity in obtaining the reading. For this reason, this type of indicator is almost universally used in meters.

This is not to say that ammeters and voltmeters do not operate on the principle of a permanent magnet and a moving coil. Many types do have this kind of meter movement; but you will find that the ammeters that you use at an advanced base are of the fixed coil-moving iron vane type.

In the moving iron vane type of meter, the magnetic field of the fixed coil (or coil system) carrying the operating current causes one or more pieces of soft iron to move. The magnetic field about the energized field is nonuniform. As a result, the iron vane (or vanes) tends to move close to the inner diameter of the coil, where the field is strongest, and the attached pointer is thereby made to move along the indicating dial.

CURRENT, VOLTAGE, AND POWER METERS

Because of the basic relationships between voltage, current, and resistance in a simple circuit, the type of device used to measure current could equally well indicate voltage, PROVIDED the resistance in a circuit remained constant.

In actual practice, different meters must be employed to measure current and voltage, but you will see that they are very similar in their operating principles. However, there are important differences in the way in which these instruments are connected into the line, since the current must always be measured in series with the circuit load, and the voltage is measured across the circuit.

Ammeter

The ammeter is a device for measuring current. You can use it to measure total current through a circuit; or you can use it to measure current through only a portion of a circuit. Figure 5-2 illustrates these two uses. The meter identified as A1 measures the total current through the branches A, B, C, D, and E. The meter identified as A2 measures the current through branch B only.

Since the function of an ammeter is to measure current, it must always be connected IN SERIES with the line, and with the load on the line. It must never be subjected to a current higher than the rating of the meter.

In the type of ammeter used at advanced bases, the coil through which the measuring current flows is fixed to the instrument frame. The magnet is a movable vane of iron or of special alloy, as indicated in figure 5-3. Magnetism induced in the iron by the current in the field coil will always have the same polarity as that of the coil, when alternating current flows in the coil. That is, when current reverses in the coil, the polarity of the magnetism induced in the moving iron also reverses.

The instrument is calibrated in terms of the unit of ampere, and rated according to its current-carrying capacity. Because of the fixed relationship in polarity, between field flux and moving vane flux, the instrument could be

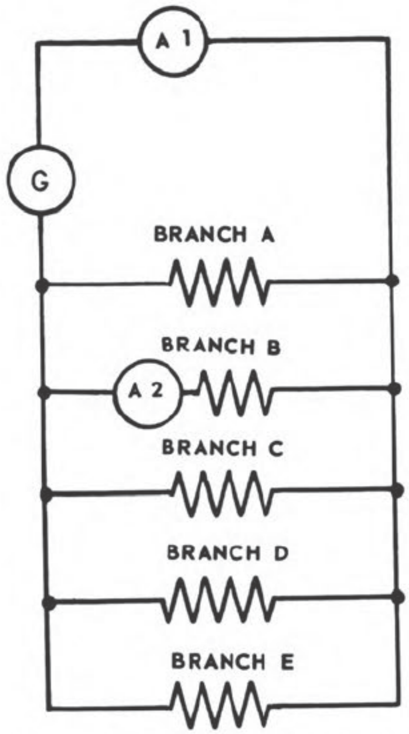
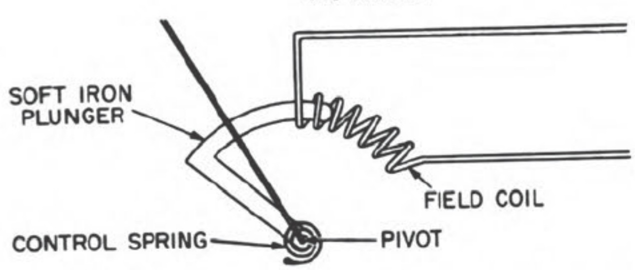


Figure 5-2.—Metering current in an entire circuit, and in one branch.



Courtesy of General Electric Co.

Figure 5-3.—Schematic of a magnetic-vane attraction-type ammeter.

calibrated for either alternating or direct current. In the latter case, however, the meter could not indicate the polarity of the current.

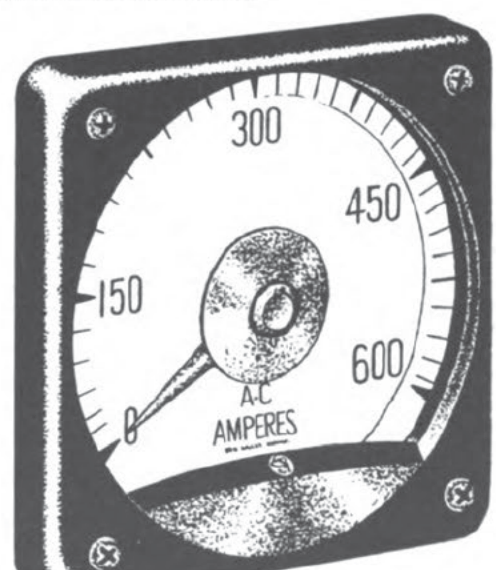
The field coil must supply all the energy necessary to operate the meter movement; any meter of a given rating, and operating on the moving vane principle, requires more power than would a moving coil type meter of the same rating. The moving vane type can carry this higher value of operating current, since the current flows through a stationary circuit.

However, there are certain limitations on current ranges. For example, the size of the instrument places the primary limitation on possible current rating; the maximum amount of heat that can be dissipated is dependent upon the size of the meter, and the size of the connecting terminals also depends upon the size of the meter.

An additional limitation is imposed upon the so-called multirange ammeters (those equipped with one or more shunts), because of the requirements of the range-switching mechanism. The particular consideration here is to keep the size of the mechanism switch within practical limits; a switch with the necessary low contact resistance for very high currents would probably be too large for the meter case.

Some examples of maximum currents that can be measured by various types of ammeter will be helpful here. The switchboard instruments usually are calibrated to indicate current up to 600 amp; figure 5-4 illustrates one of these instruments. Large portable ammeters may have calibrations up to 100 amp. Multirange ammeters are usually calibrated for not more than 60 amp.

Ammeters on individual electric equipments usually carry extremely small currents; they are rated in milliamperes, or even in microamperes. (Conversion figures for amperes, milliamperes, and microamperes are given in appendix II of this text.)



Courtesy of General Electric Co.

Figure 5-4.—Typical switchboard ammeter.

In chapter 2 of this training course, you saw how the use of a shunt resulted in sending a low, practically constant current through the field windings of a motor. This same principle is used in some ammeters; with an added resistance connected around the meter movement, the meter itself can be made to carry only a small fraction of the total current in the circuit.

Figure 5-5 shows the diagram of an ammeter with two shunts. Either one can be used, or both used, depending upon the value of the current that is being measured. The shunts in this illustration are INTERNAL—that is, they are installed inside the meter case. These are fixed shunts, so that once the meter is installed in a circuit, the shunts (or the single shunt selected) become a part of the circuit.

EXTERNAL shunts—those that are installed on the outside of a meter box, or on the back of a switchboard—can be changed if necessary, so as to increase the range of the meter. Although you are not supposed to make any adjustments on meters, there may be an occasion when you have no instrument available that suits a special need, and will have to improvise from what is at hand.

The shunting method described here is not really satisfactory for ammeters that operate on the fixed coil-moving vane principle. A shunt is entirely satisfactory on a moving coil instrument, to extend the meter range to include higher current values. The moving iron element, however, is much less sensitive than the moving coil, and would require a greater voltage drop across the shunt than would a moving coil meter.

Greater voltage drop would cause greater heating in the shunt; greater heating would require increase in size, in order to safely dissipate the heat. At the points where the instrument leads are connected to the instrument and to the shunt, contact resistance could cause a drop in voltage large enough to influence the reading. Every time the instrument were used, contact resistance could be different, and therefore it would be difficult to correct for the error in reading.

Another difficulty about applying a shunt to the a-c ammeter lies in the difference in inductive reactance of instrument coil and shunt. With changes in frequency, the impedance of the shunt remains practically the same, whereas the impedance of the coil may be noticeably affected. Thus a shunted a-c instrument can

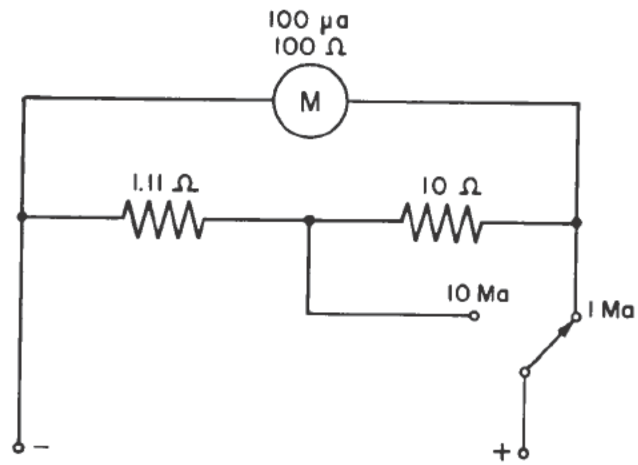


Figure 5-5.—Multiple shunt ammeter.

be expected to read accurately only at the calibrating frequency.

Most multirange a-c ammeters have two scales, one of which is exactly double the other in ampere values. The method used to provide these two ranges is as follows: The field coil, instead of being wound with a single conductor, is wound with two parallel conductors. Thus the winding is really two equal sections, each of which bears an identical relation to all other parts of the instrument.

The ends of the two sections are usually brought to separate terminals; in some instruments, they may be connected to a switch built into the instrument. Either arrangement makes it possible to connect the two windings in series or in parallel, as desired.

When it is desired to use the low current range, the windings are connected in series; to use the high current range, parallel connection of the windings is needed. On the ammeters that you will use, choosing the current range will probably be done by a selection of terminals.

If you must connect an ammeter into a circuit whose current value is unknown, select the highest possible range, and work down gradually, until you find the proper range. It is not wise to accept a range if the reading is at the upper point; you are sure of a more accurate reading if the pointer comes to rest at least a short distance from either end.

In this connection, it might be well to warn you not to use an ammeter whose highest calibrated value is the same as the expected

current in the circuit into which it is to be connected. For example, if you are going to meter a current that you believe to be 5 amp, use a 10-amp ammeter rather than a 5-amp one.

Some d-c ammeters have a scale in which zero is centered on the dial, instead of being at the far left, as in figure 5-4. On this zero-center type of instrument, current can be read in either direction.

You will find this type of ammeter used in shop work, or any place where it is necessary to read the current in a storage battery circuit. The two scales, diverging from the center of the dial, make it possible to read either a charging current, or a discharging current.

As mentioned earlier, some of the information given here is designed to help you to understand the operating principles of the ammeter, in order that you may make an intelligent use of the available instruments. Let us now sum up the FACTS that you MUST know in relation to ammeters.

1. Always connect an ammeter in series with the line and with the load. If it were connected in parallel, full line voltage would send a tremendous surge of current through the meter movement, and this surge would shortly burn out the delicate coil.

2. Never connect an ammeter to a circuit through which the current is higher than the rating of the meter, or even equally high.

3. If the current to be measured is of unknown value, start with the highest current range available, and use successively lower ranges until you find the range that gives the proper reading.

4. Be careful, when connecting an ammeter into a circuit, not to connect it so as to get a reverse polarity.

Voltmeter

A voltmeter is a device for measuring the voltage in a circuit; that is, it measures the difference in electrical pressure between two selected points. As mentioned in chapter 2 of this training course, you will find this difference in electrical pressure referred to as potential difference, or as voltage drop.

Figure 5-6 is an illustration of a commonly used type of voltmeter. Notice the double scale on the dial of this instrument; there will be an explanation of this later in this section.

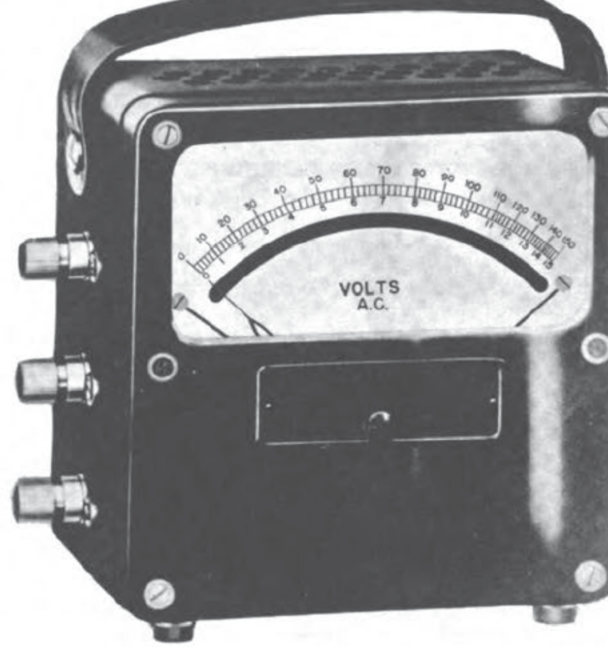


Figure 5-6.—Voltmeter.

Voltmeters must always be connected IN PARALLEL with the circuit to be measured.

If the resistance in a circuit could be held constant, and if it stood in such relation to the voltage that only a very small current could flow through the circuit, an ammeter could be used to measure voltage as well as current. Of course, the instrument dial would have to be calibrated so as to read the corresponding amperes and volts.

In practical use, however, resistance is seldom constant; but the basic principle of direct relationship between voltage, resistance, and current can nevertheless be utilized. This is done by adding a fixed resistance (other than the resistance of the coil) to the meter movement, and calibrating the scale in volts.

Both a-c and d-c voltmeters, therefore, determine voltage by measuring the current which the voltage is able to force through a high resistance connected IN SERIES WITH THE METER MOVEMENT. The construction and the operating principle of the voltmeter are similar, therefore, to the construction and operating principle of the ammeter. The schematic of a voltmeter is shown in figure 5-7. As you can see, by inspecting the illustration,

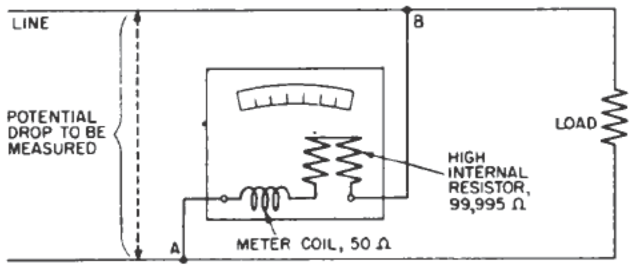


Figure 5-7.—Schematic of a voltmeter.

the instrument has a fixed resistance in series with the coil of the meter; the meter itself, however, is connected across the line.

Because the voltmeter is connected across the line, changes in load have no effect upon its reading. But every voltage across A and B will produce its corresponding current, and every value of current will cause a corresponding deflection of the pointer.

The high resistance built into a voltmeter gives it a certain degree of protection, so that the instrument is more rugged than an ammeter. In the case of the ammeter, connecting it across the line will almost immediately cause the meter to burn out; but if the voltmeter is mistakenly connected in series with the circuit, the movement will not be damaged (except by a voltage much higher than the meter range).

More than one fixed resistor may be connected INSIDE the voltmeter, and the dial calibrated to show a scale for each resistor. Figure 5-8 shows the schematic of a voltmeter with three fixed resistors, and consequently three ranges.

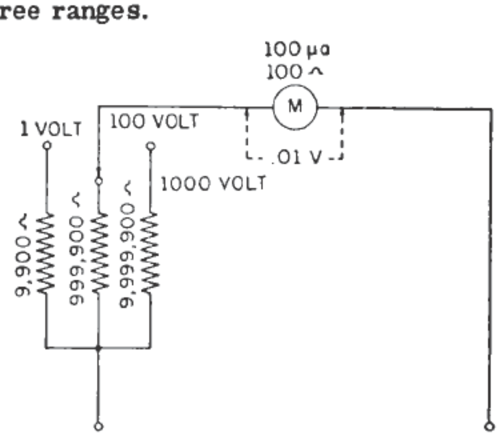


Figure 5-8.—Multirange voltmeter..

In multirange voltmeters, the meter movement is designed to operate up to full scale on the lowest range. Higher ranges are obtained by selecting the additional resistor (or resistors) of the required value. But since a low-rated voltmeter draws more current than a higher-rated voltmeter, combining a lower range instrument with a higher range one calls for higher power consumption. Therefore, any multirange voltmeter must be so designed that it can dissipate the additional heat.

There is always the possibility of reading errors due to high temperatures, and it has been found practicable to impose a limit on the number of ranges that can be combined in a single instrument.

Most voltmeters are calibrated to show one of the following ranges: 0 to 10 volts; 0 to 100 volts; 0 to 300 volts; 0 to 500 volts. There are also instruments that are calibrated in millivolts, or even microvolts, for measuring small voltages; and there are instruments calibrated in kilovolts, for measuring very high voltages. The formulas for converting volts to microvolts, millivolts, and kilovolts are given in appendix II of this training course.

The correct voltage range to use can be readily chosen when approximate line voltage is known. If you do not know the approximate voltage in the circuit to be tested, always select the highest range available. You can then choose lower ranges, in successive tests, until a suitable reading is obtained.

In most cases, you will be working with voltages of less than 600 volts. If an occasion arises when you have to measure a higher voltage—certainly when you must measure a voltage as high as 750 volts—it may be necessary to adapt an available meter to accommodate this higher load.

This can be done by adding an external resistor, or MULTIPLIER, as it is usually called. This additional resistor, if absolutely required, should be taken care of by a trained repairman, or by an experienced high-rated man.

The following points are the ones which you must always bear in mind when using a voltmeter:

1. Select a voltmeter with a range suitable for measuring the voltage of the circuit to be tested.

2. If the approximate voltage of the circuit to be tested is unknown, start with the highest voltage range, and use successively lower ranges until you obtain a suitable reading.

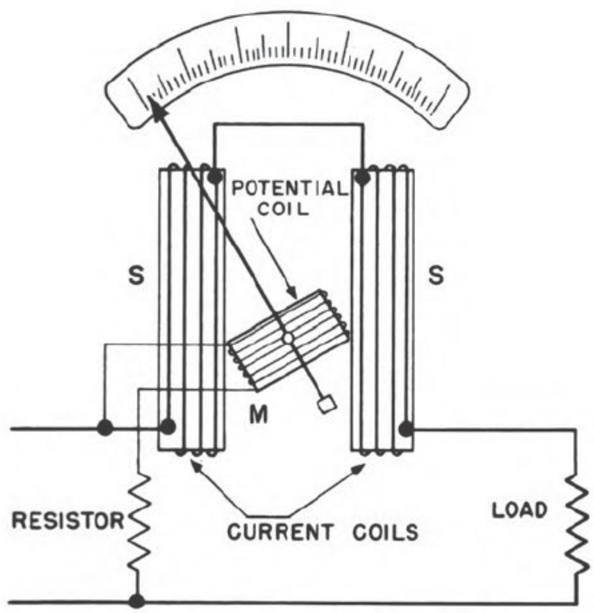
3. Connect the instrument IN PARALLEL with the line and with the load.

4. Take care to connect the positive terminal of the meter to the positive terminal of the source, and the negative terminal of the meter to the negative terminal of the source. This ensures that meter polarity matches the polarity of the circuit in which the meter is placed.

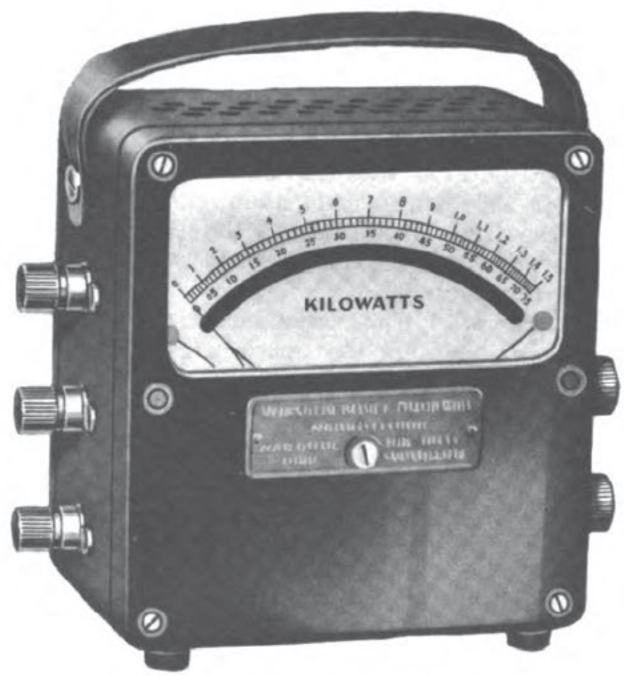
It is possible to measure alternating voltage, and current also, without breaking into a circuit. This is done by using the clamp-on voltammeter, described in a later section of this chapter.

Wattmeter

Current, voltage, and resistance are the electrical factors that we associate with an electrical circuit; but for a true power measurement of an a-c circuit, we have to use a wattmeter. Figure 5-9 shows a wattmeter, and a diagram of its circuit. The heavy lines in the diagram represent current-carrying coils.



CIRCUIT



EXTERNAL VIEW

Figure 5-9.—Diagram of a wattmeter circuit, and an external view of the instrument.

Since power is dependent upon both voltage and current, a change in one of these factors in a circuit will change the amount of power delivered. For an a-c circuit, therefore, power taken as the product of voltage and current varies somewhat from instant to instant. The function of the a-c wattmeter is to provide a reading that indicates the power actually being delivered.

As you can see from the diagram in figure 5-9, the wattmeter utilizes the principle of two coils (current and potential), with a pointer attached to the moving coil.

A single phase wattmeter can be used to measure either alternating or direct current power.

A three phase wattmeter consists essentially of two single phase wattmeters, with the moving elements mounted on a common shaft, and with a single pointer to indicate values. A wiring diagram is provided with these instruments, and this diagram must be carefully followed in order that the instrument itself will make the necessary additions and subtractions between values recorded by each individual meter.

If a three phase wattmeter is not available, it is possible to measure three phase power with two separate single phase wattmeters. This can be done regardless of whether the loads on the phases are balanced. The voltage coils of each meter are connected to one phase; then the current coils of the meters are connected, one to each of the other phases.

If the load on the three phase system is balanced, and the power factor is known, it is a simple matter to obtain a reading. (Even on a balanced system, the readings are not usually identical.) For a power factor greater than 0.5, add the readings; for a power factor less than 0.5, subtract the smaller value from the larger.

When the load is unbalanced, or when the power factor is unknown, it will be necessary to make a check before you can know whether to add or subtract the readings.

There are several methods of checking the two wattmeters, but the simplest one is to turn off the power, and then connect a lead from the first wattmeter to the line to which the current coil of the second wattmeter is already connected.

Figure 5-10 illustrates how these connections are made. In the upper part of the diagram, wattmeter 1 has its current coil connected to line A, and its voltage coil to line C; Wattmeter 2 has its current coil connected to line B, and its voltage coil to line C. When these connections have been made, take the readings from both wattmeters.

After the readings have been noted, turn off the power, and connect Wattmeter 1 to line B at the point D, as indicated in the lower part of the illustration. (It is possible to make the check with Wattmeter 2, if preferred, by connecting it with line A.)

When the power is turned on, read the meters; if both read in the same direction (either up scale or down scale), add the readings. If one reads up scale, the other down, subtract the smaller reading from the larger.

Current and voltage ranges are important, since it is possible to burn out the coil in an instrument which has been properly connected, and the pointer of which is indicating only a fraction of full scale. This is where a knowledge of what is meant by power factor is involved.

As an example, suppose that a wattmeter has a 5-amp current coil, and a 100-volt potential coil. If the power factor were 100 percent, the instrument would read 500 watts full scale. If the power factor were only 0.5 (that is, 50 percent), full scale would be only 50 percent of 5 amp times 100 volts. And if the pointer indicated the full 500 watts on the scale, then either the current coil or the voltage coil would be overloaded, since when

E times I times 0.5 equals 500 watts,
E times I equals 1000 volt-amperes,

which is just double the load that the wattmeter is designed to measure.

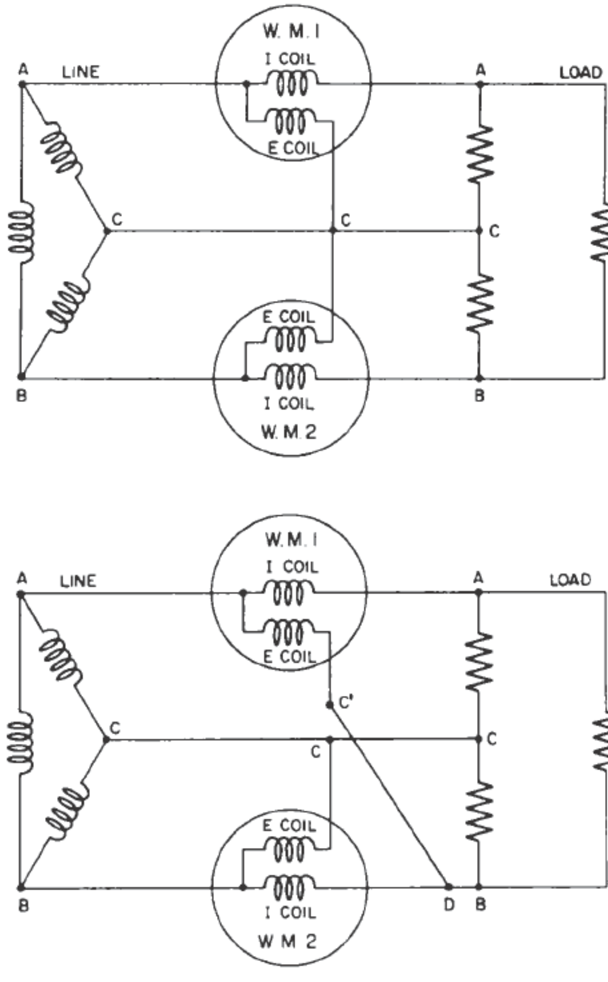


Figure 5-10.—Two-wattmeter method of determining power.

It is important, therefore, that the maximum current and the maximum voltage of a wattmeter be known before it is put to use; and it is equally important that the values to be supplied should not be much greater than these maximum figures.

Power Factor Meter

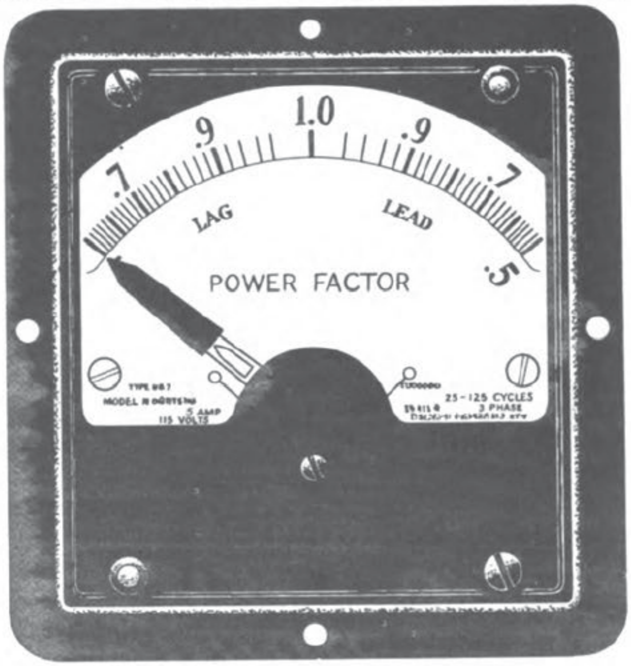
Power is not only useful power expended in the load, but it is also reactive power. This last contributes to the load carried by the conductors, but not to the work performed by the electrical circuit. Power factor is known as RMS value (root mean square), because it is the ratio of useful power to the square root of the sum obtained by adding the square of useful power and the square of reactive power.

While wattmeters give the readings for the power being delivered by a circuit, they cannot indicate whether current is leading or lagging voltage. Neither do they indicate how much power is being wasted, unless you divide the product of the readings from voltmeter and ammeter into the wattmeter reading. To QUICKLY determine the power factor, it is necessary to have a power factor meter.

The principle of this type of meter is the interaction between (1) a pulsating magnetic field produced by a single coil, and (2) a rotating magnetic field, similar to that in an induction motor, produced by two or more coils. The moving element may be the single coil, or it may be the two or more coils, or it may be an iron vane magnetized by the single coil. When the single phase (single coil) field has its maximum value, the rotating field is alined with it.

Most power factor meters are designed so that when current lags voltage, the pointer moves to the left of the central position on the scale; when current leads voltage, the pointer moves to the right of the central position. This central position indicates a power factor reading of one, and is usually referred to as the unity mark.

Figure 5-11 represents a type of power factor meter, and figure 5-12 shows the meter connections in a 3-phase 3-wire circuit.



Courtesy of General Electric Co.

Figure 5-11.—Power factor meter.

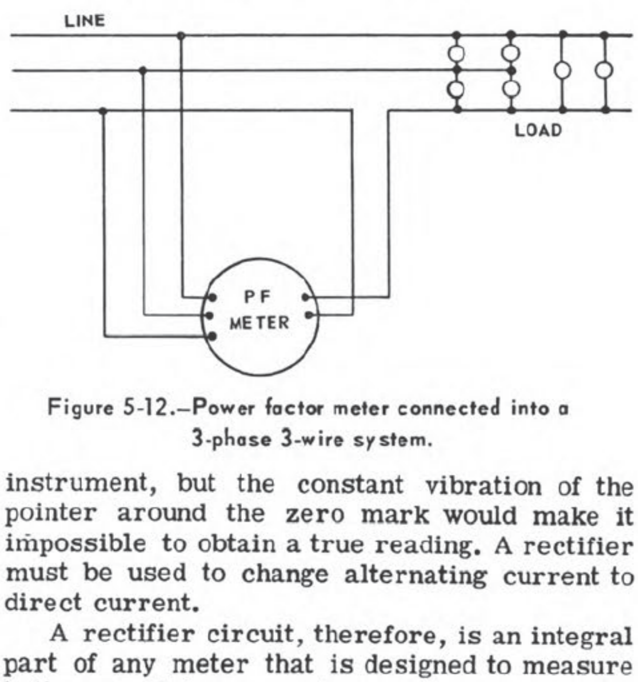


Figure 5-12.—Power factor meter connected into a 3-phase 3-wire system.

Rectifier

In the discussion of ammeters, reference was made to the fact that a current sent in the wrong direction through a coil may send the pointer off scale, and damage the instrument. On those meters where the zero mark is centered on the dial, constant reverses in direction would not necessarily damage the instrument, but the constant vibration of the pointer around the zero mark would make it impossible to obtain a true reading. A rectifier must be used to change alternating current to direct current.

A rectifier circuit, therefore, is an integral part of any meter that is designed to measure both a-c and d-c current.

Clamp-On Voltammeter

As mentioned earlier, it is possible to measure current flow in a circuit without disconnecting leads or otherwise deenergizing the

circuit. The device by which this can be done is the portable clamp-on voltammeter, illustrated in figure 5-13.

This device can be clamped around a conductor, of either bare or insulated wire, and will give the effective reading of alternating current as soon as you move the selector switch to the suitable scale. To read a-c voltage, you must connect the leads from the terminals of the instrument to the circuit being tested, and then move the selector switch to the proper voltage scale.

The selector switch provides a choice of several current ranges and voltage ranges. For example, current ranges might be as follows: from 0 to 15, from 0 to 60, from 0 to 150, and from 0 to 600 amp; and the voltage ranges might be from 0 to 150, and from 0 to 600 volts. These are the ranges on the voltammeter illustrated in figure 5-13. This instrument has a 6-position selector switch; there are 4 positions for selecting amps, and 2 for volts.

Since the switch is mounted just above the handle of the voltammeter, it can easily be operated with the same hand that holds the instrument. It is also possible to measure both the current and the voltage with one hook-up.

Figure 5-13.—Clamp-on voltammeter.

Figure 5-14A illustrates reading both current and voltage with a single set-up; B of this figure represents reading voltage only. To read current value, the selector switch must

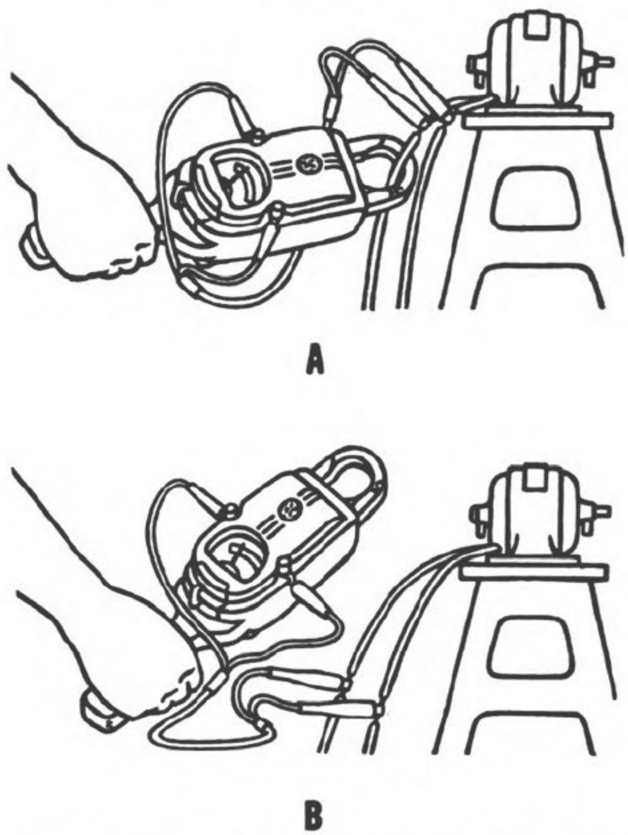


Figure 5-14.—Determining alternation current and voltage with a single set-up: A, reading voltage and amperage; B, reading voltage only.

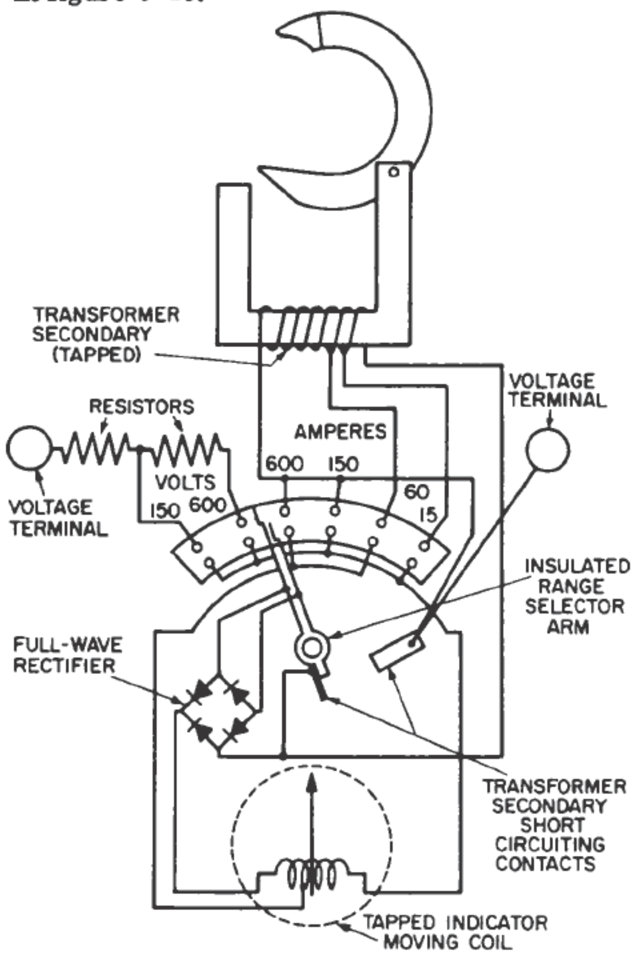
be set at AMPERES, to read voltage it must be set at VOLTS.

In order to read voltage, it will be necessary to have the leads connected from the voltage terminals on the meter to the terminals across which the voltage is to be measured. Leaving the voltage leads connected does not affect current reading when the instrument is hooked around the line, and the switch is thrown to AMPERES.

The operating principle of the voltammeter consists of an indicating element that is deflected according to the strength of the magnetic field around a current-carrying conductor. Coupling between field and element is obtained by clamping the split core around the conductor.

The core is hinged. The dovetail joint that closes around the conductor in the application

of the voltammeter provides the one complete break in the magnetic circuit. A diagram of the internal circuit of the voltammeter is shown in figure 5-15.



Courtesy of General Electric Co.

Figure 5-15.—Internal connections of the clamp-on voltammeter.

To attach the instrument to a conductor, open the split core transformer manually, and then place the instrument so that the conductor runs through the dovetail joint. A push on the instrument handle will close the dovetail joint of the core around the conductor.

The position of the conductor has very little effect upon the accuracy of the reading. When you are ready to remove the voltammeter, you can open the transformer core by pulling GENTLY on the handle.

The split core is large enough to enclose conductors up to two inches in diameter. If you are measuring currents of small value (one or two amp), you may find it advisable to extend the current range, to provide a more reliable reading. In order to do this, loop the conductor two or three times through the transformer core, as indicated in figure 5-16. Then divide the current reading by the number of loops, to get true current value.

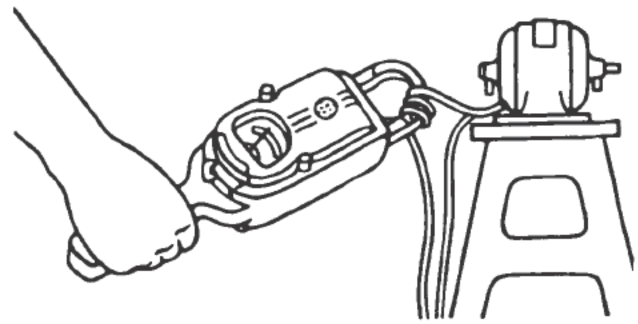


Figure 5-16.—Looping the conductor to extend the current range of the voltammeter.

There are attachments available to use with the voltammeter, when there is not enough slack in a conductor to permit wrapping it around the core. Even when there is enough slack, there is always the danger of pulling loose or breaking small conductors. If you have the attachment, it is always advisable to use it, in preference to making loops in the conductor.

The accuracy of these voltammeters is less than that of switchboard meters, but they nevertheless can be useful tools in trouble shooting and in maintenance work. One necessary precaution is to keep the pole faces clean, and to make sure that they have good contact. A poor contact, because of dirt or wear, will cause the reading to be in error.

Multimeter

The multimeter is a general purpose instrument that can be used for measuring direct as well as alternating current and voltage. One type of instrument is the circuit tester, or multivolt ohmmeter. (More often, it is referred to by the term used here, multimeter.)

For measuring either voltage or current, the multimeter has various scales. For example, the voltage scale may go as high as 1,000 volts d-c, and 750 volts a-c. The current scale may be in amperes, in milliamperes, or in microamperes. Meters with milliampere and microampere scales are for d-c only; the milliampere scale is chiefly used for taking armature

bar-to-bar tests. Instruments with ampere scales are for use with a-c or d-c.

Several scales for measuring resistance are also provided. For example, resistance scales might run from zero ohm to eight megohms. When resistance is being measured, the instrument is energized from dry cells contained in the case.

A-C Power-Circuit Analyzer

To check electrical loads and circuit characteristics in single phase or in three-phase systems, you can use an a-c power-circuit analyzer, illustrated in figure 5-17. The portable instrument consists of ammeter, voltmeter, three-phase wattmeter, and power factor meter, mounted in a single case.

Although these instruments must be individually connected within the case, combining them makes it possible to eliminate the complicated hook-ups that are often necessary when the individual meters are used separately.

Maximum range of this instrument is: 600 volts, 125 amp, and 75 kilowatts. Usual range is 220 to 440 volts.

DEVICES FOR MEASURING RESISTANCE

The two devices commonly used to measure the resistance of a circuit or a circuit component, or to check continuity in a circuit, are the ohmmeter and megger (megohmmeter).

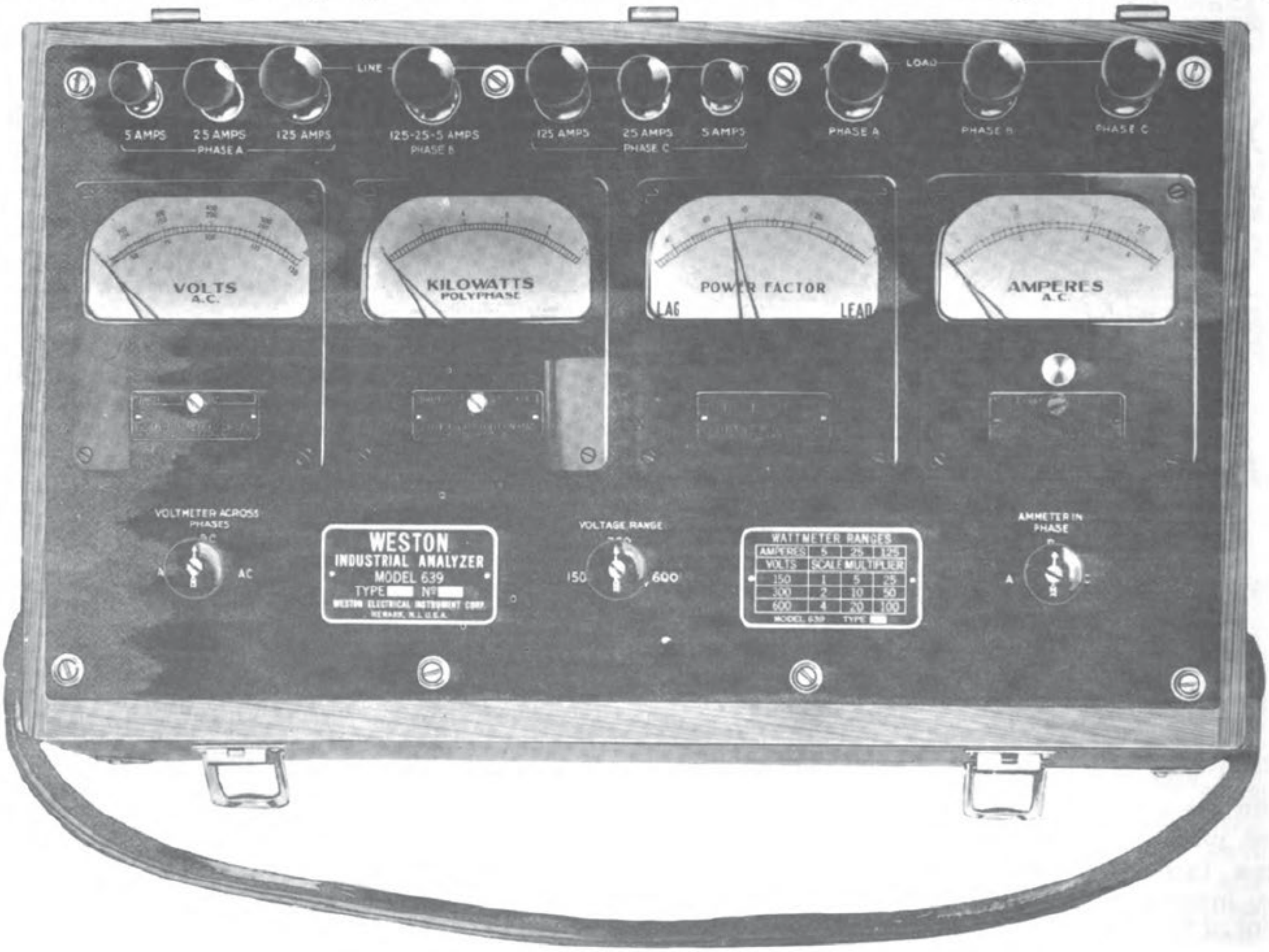


Figure 5-17.—A-C power circuit analyzer.

The range of an ohmmeter is usually only a few megohms, but the range of the megger is much greater. This much higher range is necessary because the megger is used chiefly for testing the very high resistances of insulation, cable, bushings, and so forth.

Ohmmeter

An ohmmeter is used to measure resistance when extreme accuracy is not important. A more accurate reading of the unknown resistance in a circuit can be obtained by inserting a known value of fixed resistance in series with the resistance to be measured. The fixed resistance so inserted in the ohmmeter circuit is known as a multiplier.

A range selector switch allows the choice of the range on the dial, or of the use of multipliers—for example, 10, 100, or 1,000. If the multiplier 10 is used, the actual resistance is 10 times the reading indicated on the dial; with the 100 multiplier, the resistance is 100 times the dial reading; with the 1,000 multiplier, the resistance is 1,000 times the dial reading.

Figure 5-18 illustrates the dial of an ohmmeter. Notice how the scale contracts as the resistance becomes higher.

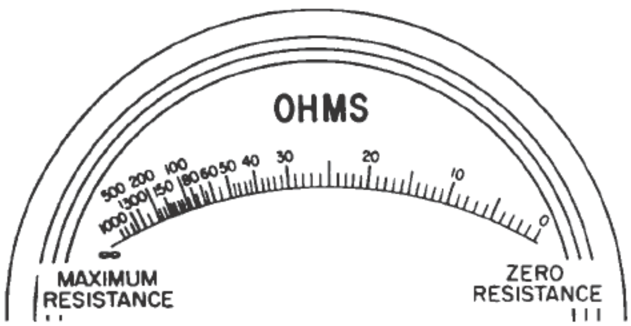


Figure 5-18.—Ohmmeter dial scale.

Each time the range is changed by use of the selector switch, the meter must be "zeroed," since zero varies slightly for each range. Put the test leads in the ohmmeter jacks marked RES OHMS; then touch the test prods together, to see if the meter deflects to full scale.

Since an ohmmeter depends upon a primary cell for voltage, and since the cell loses capacity with use, there is always a rheostat in the ohmmeter circuit, to compensate for decrease in battery capacity. If this rheostat cannot bring the meter pointer to zero, the battery must be replaced.

This is a good point at which to describe the makeup of an ohmmeter. A series type ohmmeter contains a small dry-cell battery that furnishes enough voltage to cause full scale deflection of the meter indicator. Battery, meter coil, and resistance are all series connected. When the test prods are brought together, there should be full scale deflection of the indicator.

However, using the ohmmeter on a circuit places a new resistance between the prods. This additional resistance is also in series, and since the battery voltage is not changing, the added resistance has the effect of reducing current. The indicator, therefore, will read something less than full scale deflection. The amount of the reading is the measure of the unknown resistance of the circuit placed between the prods.

In a shunt ohmmeter, battery and rheostat are in series, but the unknown resistance is connected in parallel with the meter coil. Current drawn from the battery can go through the coil, or through the unknown resistance (that is, the resistance to be measured). This unknown resistance acts as a shunt resistor for the meter. Figure 5-19 illustrates basic ohmmeter circuits.

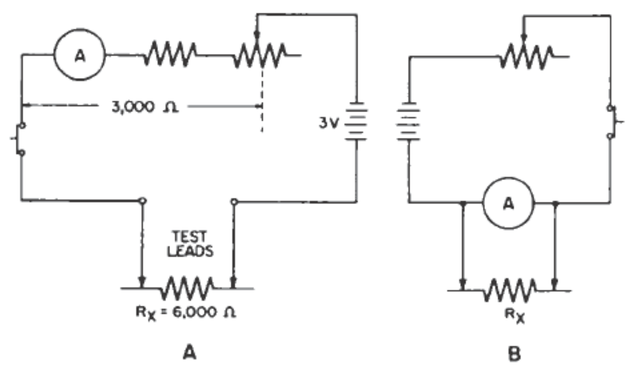


Figure 5-19.—Basic ohmmeter circuits: A, series; B, shunt.

When the prods are touched together, the meter reads zero; when the external resistance is connected through the prods, the pointer deflects. If the unknown resistance is high, most of the current goes through the meter coil, and deflection is high. If the unknown resistance is low, most of the current passes through it, and the deflection is low. The meter is so calibrated that the resistance can be read directly in ohms.

A study of the basic diagram of the shunt ohmmeter makes it clear that even when there is no external resistance placed between prods, there is still a path of current flow through the meter, and the battery will be discharging, although the instrument is not in use. To

prevent this, a shunt ohmmeter is provided with a switch. Always open this switch as soon as you have finished using the ohmmeter.

Remember that you should make sure that the ohmmeter pointer rests at zero before you measure resistance in a circuit. There is another more important precaution: BEFORE YOU PLACE AN OHMMETER IN A CIRCUIT, MAKE SURE THAT THE CIRCUIT IS DE-ENERGIZED.

Megger

The megger consists of an indicating movement for which the required current is supplied by a small, hand-driven generator. The generator is used because it would require an excessive number of batteries to furnish the amount of current needed.

Permanent magnets provide the flux field for the generator, which is therefore commonly called a magneto. A crank mounted on the side of the megger provides the means for turning the armature through the field.

Figure 5-20 shows a simplified megger circuit, and an external view of the megger.

In the illustration, A and B represent the opposed coils. These coils are mounted on a movable member, and have a fixed angular relationship to each other. Coil A tends to move the pointer clockwise; coil B tends to move it counterclockwise. C indicates the stationary iron core. R2 represents the resistance in the voltage circuit; R3 represents the resistance in the current circuit; and RX represents the resistance between EARTH and LINE terminals.

When the crank is turned, with nothing connected between the earth and line terminals, no current flows in coil A; coil B moves to a position opposite the gap in the core, and thus causes the pointer to move to INF (infinity).

With a resistance connected across the terminals, current flows in coil A, and a proportionate torque draws coil B away from the infinity position into a field of gradually increasing magnetic strength. When balance is obtained between the forces acting on the two coils, the pointer indicates the amount of resistance.

Because both coils receive current from an identical source, change in generator voltage will affect both coils in the same proportion.

DEVICES FOR MEASURING FREQUENCY AND TOTAL REVOLUTIONS

The usual instruments employed by the Construction Electrician for measuring the speeds of electrical equipments are frequency meters, revolution counters, and revolution indicators. You may sometimes hear these latter two devices referred to as tachometers. Actually, a tachometer is any device which measures speed in rpm's, so the use of the term is technically correct. However, since there is a difference in the method in which revolution counters and rotation indicators measure rpm's, the specific names of these devices are used here, to avoid confusion.

If two a-c generators (alternators) are connected in parallel, frequencies and voltages must be equal. The generators must also have the same phase sequence—that is, they must be in phase.

A voltmeter is used to determine if voltages are equal. A synchroscope (described in a later section of this chapter) can be used for determining proper in-phase relationship. To adjust the frequency of the incoming alternator, so that frequencies will be equal, a frequency meter is needed.

(The PROCEDURES for paralleling two alternators are discussed as part of the operation of a generating station, in chapter 7 of this training course.)

Frequency Meter

All a-c systems and equipment are designed to operate normally at a particular frequency. For advanced base equipment, the frequency is 60 cps (cycles per second). The range of a frequency meter, therefore, can be restricted to a few cycles on either side of normal frequency. The meter is so designed, too, that it will not be affected by changes in voltage.

Different types of frequency meters operate on various combinations of fixed and moving coils, or of fixed coil and moving iron, with the end result of producing a pointer deflection that reads the frequency of the system.

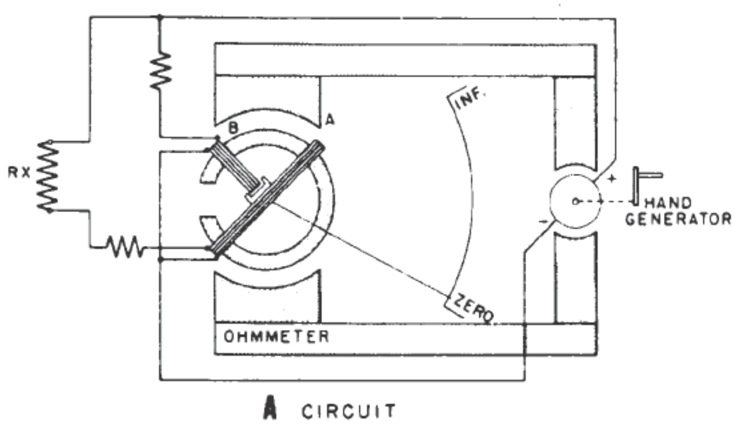
In the most modern instruments, two series-resonant circuits provide the necessary deflecting torque by utilizing the frequency-versus-reactance characteristics of the two circuits. The torque provides the action on the meter indicator.

However, the vibrating-reed type of frequency meter, though not so modern, is the type with which you are most likely to be concerned. A diagram of this type of meter is shown in figure 5-21.

The current whose frequency is to be measured flows through the coil shown at A of this figure. As the current passes through the coil, it exerts maximum attraction on the soft-iron armature TWICE during each cycle.

The armature is attached to the bar, which in turn is mounted on a flexible support. Reeds with specific resonant frequencies are mounted on the bar, as indicated in B of figure 5-21. These reeds are marked with ONE-HALF the value of their natural vibration frequencies. That is, a reed that vibrates at a frequency of 110 cps is marked "55 cycles;" one that vibrates at a frequency of 120 cps is marked "60 cycles."

At C of the figure, you see an end view of these reeds, as they occur in the indicator dial of the meter.



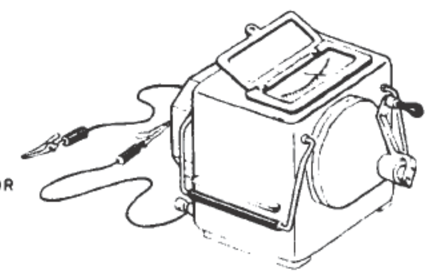


Figure 5-20.—Megger and megger circuit.

When the coil is energized with a current having a frequency between 55 and 65 cycles, all the reeds will vibrate slightly, but the reed that has the natural frequency closest to that of the energizing current will vibrate through a larger amplitude. The frequency is then read from the dial.

In some instruments the reeds are all of the same length; in such a case, they are weighted by different amounts, to give them different rates of vibration.

Since the function of a frequency meter is to indicate the cycles per second of the generated power, these meters are used to adjust the power source, and thus ensure the required frequency for time switches, electric clocks, transformers, motors, and other types of a-c equipment connected to the supply source.

In any cases, exact frequency is necessary. For example, if a clock is designed to operate on a supply frequency of 60 cps, a frequency of 61 cps will cause it to gain one minute every hour; a frequency of 58 cps will cause it to lose two minutes every hour. In general, if supply frequency falls more than 10 percent from rated value, the equipment may draw excessive current, and overheat to the point of danger.

Revolution Counter

If it should become necessary to determine the speed of a moving shaft, you can do so by means of a revolution counter or a rotation indicator. Such devices are frequently referred to as tachometers.

Tachometers give a DIRECT reading, on the dial, of the rpm of a rotating shaft. On some types, no timing is necessary, and any variations in shaft speed are reflected in the movement of the pointer.

On some equipment, tachometers are used in place of frequency meters.

There are several types of tachometers or indicators that can be used for indicating shaft speeds from remote positions. For example, the type employed may be:

1. A d-c generator type, with a voltmeter indicator.

2. A a-c generator type, containing a transformer, and a rectifier-type a-c voltmeter

3. A 3-phase a-c generator type, with an indicator using a synchronous motor operating a magnetic-drag assembly

The first two types are usually switchboard mounted, although the d-c type with voltmeter indicator can be a portable instrument. The third type is attached to the rotor of the synchronous motor. The rotating magnets produce a torque proportionate to shaft speed, to drive the pointer.

In the case of the switchboard mounted instruments, the operating principle is somewhat different. In the d-c generator type, the generator is driven from the shaft whose rpm is to be measured. Because generator output voltage is proportional to speed, the voltmeter can be calibrated in rpm's instead of volts.

The a-c generator type is frequency-sensitive, rather than voltage-sensitive. The transformer output is proportionate to the frequency

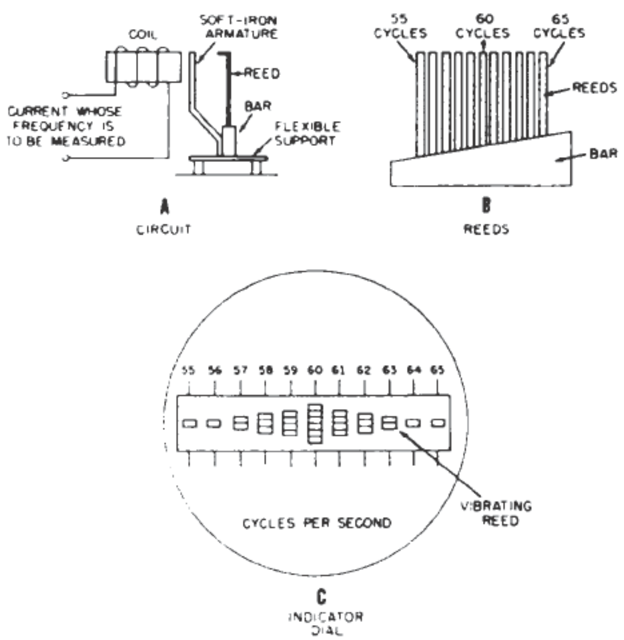


Figure 5-21.—Simplified diagram of a vibrating-reed frequency meter.

of the applied voltage, but the frequency is also proportional to the speed of the generator.

Some types of a-c tachometer equipment, used primarily to measure low speeds, may consist of the a-c generator and the rectifier-type voltmeter. Over the rated speed range, voltage output is directly proportional to speed, and the instrument dial may be calibrated in any units related to speed (revolutions per minute, or feet per minute).

Rotation Indicator

The rotation type of speed indicator has a dial calibrated for both directions of rotation. The dial itself is fixed to the frame, but a movable center disk makes one full rotation for every 100 revolutions of the shaft to which it is applied. A raised dot on the disk allows you to count the number of times it revolves. This number, multiplied by 100, and increased by the dial reading at the end of the timing period, gives the total rpm during the timing period.

Before the test, set the disk so that the raised dot is in line with the raised dot on the dial. Because the center disk is spring loaded, a slight pressure of your thumb on the raised dot will maintain the zero setting. When you are ready to make the test, raise your thumb slightly, but not so high that you will not feel the raised dot on the disk each time that it completes a rotation.

OTHER DEVICES

There are various other devices used to measure electrical properties. In this section, you will find a description of the thermocouple meter, phase sequence indicator, and synchroscope.

Thermocouple Meter

The purpose of a thermocouple meter is to measure currents at high frequencies, or at high temperatures. These meters are installed in large generators, where it would be impossible to use a thermometer.

The device consists of (1) the heating element, (2) a thermocouple, and (3) a permanent-magnet moving-coil mechanism. The thermocouple is formed by joining two wires made of dissimilar metals. Where the ends of these wires are joined, you have the hot junction or thermojunction. Where the wires are connected to the leads of the instrument, you have the "cold ends."

When heat is applied at the thermojunction, the two wires heat at different rates, and a small d-c voltage is produced. This voltage is proportional to the amount of heat applied at the junction.

Maximum current that can be measured by this device is determined by the following factors: the current rating of the heater, the amount of heat that the thermocouple can stand without suffering damage, and the current rating of the meter itself.

The controlling factors for calibrating a thermocouple are: the materials of which the thermocouple wires are made, and the difference in temperature between the hot junction and the cold ends.

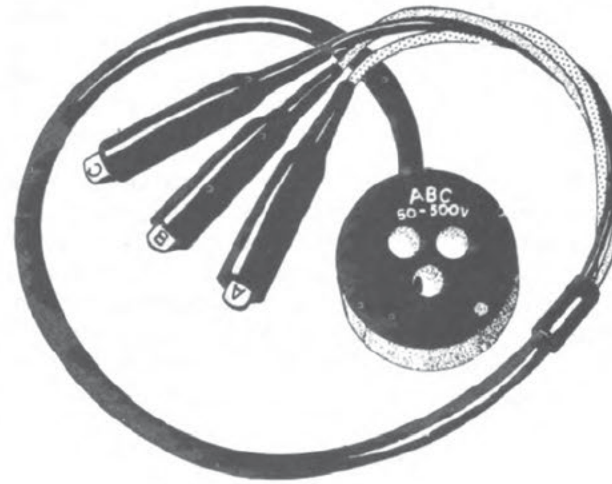


Figure 5-22.—Phase sequence indicator.

Phase Sequence Indicator

The phase sequence indicator is used to compare the phase rotation of an incoming alternator that is to operate in parallel with an alternator already on the line; or to check on the phase rotation of any electrical equipment being put into use for the first time.

The makeup of a phase sequence indicator is as follows: a tiny three-phase induction motor is equipped with three leads, labeled A, B, and C, as indicated in figure 5-22. The insulating hoods over the clips are of different colors—red for A, white for B, and blue for C—to assist in identification.

The rotor turns when connected to the power source. The ports, or holes, in the indicator case are to assist you in determining the direction in which the rotor turns. The rotor is also equipped with a momentary contact switch (contact is maintained only while the button is depressed), which enables you to start and stop the indicator as desired, in order to check the direction.

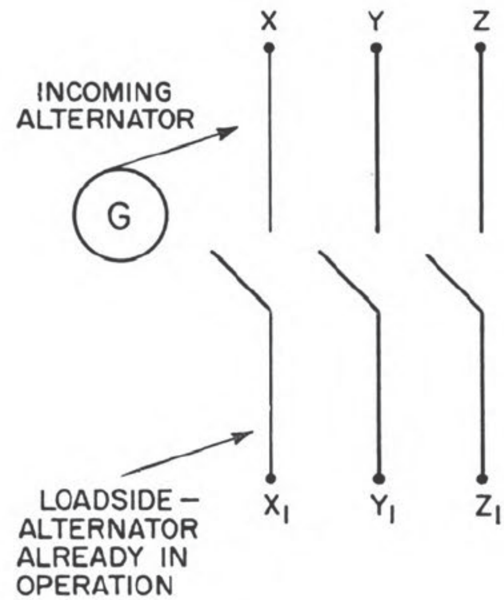


Figure 5-23.—Diagram for checking phase sequence.

The line diagram in figure 5-23 will help you in learning how to check phase sequence. Connect the phase sequence indicator A to X_1, connect B to Y_1, and connect C to Z_1. Press the contact switch on the indicator, and observe the direction of rotation of the rotor.

The next step is to move the A terminal of the indicator to X, B to Y, and C to Z, and again press the switch. If the rotor turns in the same direction as before, the phase rotation is the same. If the rotor turns in the opposite direction, transpose the connections of any two leads.

It is not absolutely necessary that A be connected to the left-hand terminal in the switch, B to the center terminal, and C to the right-hand terminal. This is a practical method, however, since it avoids the danger of mixing leads. The really important thing is that the phase sequence indicator that was used on

X_1 be moved down to X, the one used on Y_1 be moved down to Y, and the indicator used on Z_1 be moved down to Z. If any two leads are reversed, in connecting them to the switch terminals, the direction of the rotor will be reversed.

There are other types of phase rotation indicator, besides the one just described. For example, there is a type that consists of lamps set in a simple circuit containing resistance and inductance, or capacitors (condensers). The sequence in which the lamps light indicates the phase sequence. This method is described in the following chapter.

Synchroscope

The synchroscope is essentially a power factor meter connected to measure phase relation between generator voltage and bus bar voltage, when a second generator is being put on the line.

In chapter 7 of this training manual, you will see that, when two alternators are to be operated in parallel, phase sequence, voltage, and frequency must be the same for the incoming alternator and the bus bars already energized. The generator frequency must be practically constant, and the generator and bus bar voltage in phase.

Synchronizing the alternators is usually done by an arrangement of lamps, as described in chapter 7. The use of a synchroscope, however, provides greater accuracy.

The three factors that are determined by the synchroscope are: (1) if frequency of the alternators is the same; (2) if frequency is constant for a considerable period of time; and (3) if the bus bar voltages of both generators are in phase—that is, reach maximum value at the same time.

Figure 5-24 illustrates the dial of a synchroscope, and figure 5-25 shows the wiring diagram.

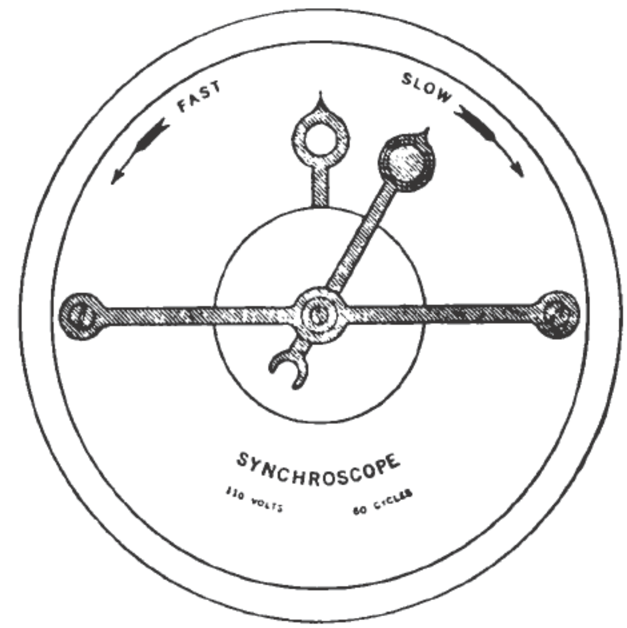


Figure 5-24.—Synchroscope.

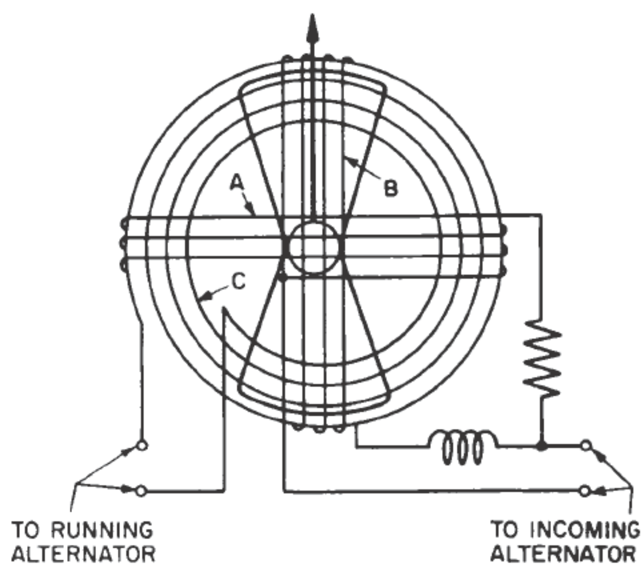


Figure 5-25.—Wiring diagram of a synchroscope.

Coils A and B (in fig. 5-25) are connected to the incoming generator; this connection is made through a potential transformer. Coil C is connected to the bus line.

One pointer holds a fixed position, at the top of the dial (see fig. 5-24). The moving element, to which the second pointer is attached, is free to rotate, but it takes a fixed position when frequencies are exactly the same. With any slight variation in frequency, the moving pointer will begin to travel, and the direction of travel shows whether the incoming generator is fast or slow. The difference in frequencies is indicated by the speed of travel.

Adjust the speed of the incoming generator until the moving pointer slows down. As it slowly approaches the stationary pointer (the mark which shows that the two voltages are in phase), cut the second generator in just before the two pointers coincide.

CONTROLS

A variety of controlling devices may be used in an electrical system. Circuit breakers, for example, are used for the purpose of taking care of exceptional power surges, of overloads, and of reverse current. Rheostats are used to vary resistance in a circuit, and for the intentional control of terminal voltage. Transformers are used for stepping up or stepping down voltage.

Discussion of such devices as fuses, circuit breakers, relays, rheostats, lightning arresters, and transformers occurs in chapters 2, 4, 6, and 7 of this training course. This section, therefore, is restricted to a description of automatic voltage regulators, and automatic and manual starters.

Although the Construction Electrician is not responsible for installing, servicing, and trouble shooting automatic controls until he makes First Class, nevertheless the lower-rated men should have some knowledge of these controls, and of the purposes they serve.

Voltage Regulators

Most automatic voltage controls are used on feeder circuits taking power from bus bars having practically constant voltage. The regulator automatically increases or decreases voltage of the outgoing feeder, to compensate for line drop or variable bus voltage.

Voltage regulators are also used at points along a high voltage distribution line, to compensate for line drop or other voltage losses.

In general, voltage regulators are not used on d-c generators. On a-c generators, however, these automatic voltage regulators are necessary, in order to maintain proper voltage during load changes.

For example, the starting current of an induction motor is from 5 to 8 times normal full-load current. Because of this high starting current, there must be a close voltage regulation, to ensure that all other devices connected to the same branch of the system will operate satisfactorily.

The field current in the a-c generator is a direct current, obtained from the exciter. With a steady load on the generator, the exciter furnishes a steady value of current. With an increased load on the generator, there is a decrease in terminal voltage.

Such a voltage decrease must be offset by increasing the value of the field current in the alternator; and the way in which this is accomplished is by changing the field excitation. This change in the alternator field-current, in response to load changes, can be done by manual adjustment, but the use of an automatic voltage regulator is faster and more efficient.

These regulators differ widely in type and design. The manufacturers' instruction manuals are the best source of information on the construction and operation of these devices. However, a description of the type of direct-acting automatic voltage regulator illustrated in figure 5-26 will provide you with a basic understanding of these regulators generally.

The principle components of this voltage regulator are the control element, the damping transformer, and the cross-current compensator. The rectox unit is a bridge-connected full-wave rectifier that serves to convert alternating current to direct current.

The control element consists of a stationary regulator coil wound on a soft iron core. Mounted on the armature is a moving arm; and attached to this moving arm is a smaller pusher arm on a coiled spring. The pusher arm carries two insulated pins, so arranged that they can be made to bear upon silver buttons.

The silver buttons are individually mounted on leaf springs, and are insulated from each other at their connections. They are connected to taps on fixed regulating resistance plates (one plate for each silver button assembly) mounted in the rear of the unit.

On small a-c generators, the regulating resistor is connected into the field circuit of the generator. On large a-c generators, the regulating resistor is usually connected into the field circuit of the exciter. Since exciter field power is less than generator field power, this latter method of connection permits the use of smaller voltage regulator equipment.

The regulator coil of the control element opposes the MECHANICAL force of the spring. The regulator coil is connected in series with a voltage adjusting rheostat. The adjustment of this rheostat determines the VALUE of the voltage applied to the regulator coil.

The second component, the damping transformer, is an antihunt device. The primary windings are connected across the output of the exciter; with any change in exciter voltage, the primary winding induces a voltage in the secondary winding. This induced voltage acts

on the regulator coil to dampen the movement of the iron core, and thereby prevent excessive changes in generator terminal voltage.

The third component, the cross-current compensator, is designed to supply compensating voltages in two legs of the three-phase regulator circuit, to ensure that the regulator coil receives a balanced three-phase voltage.

Since the basic circuits of a direct-acting voltage regulator, connected in series with the exciter shunt field, appear in figure 5-26, the diagram should enable you to follow the operating principle of this type of regulator.

When the generator is put on the line, the regulator coil of the voltage regulator is energized, and there is a magnetic pull on the armature. As long as voltage remains constant, the pull on the armature is balanced by the tension of the pivot spring.

If the pull on the armature and the tension of the spring are unbalanced forces, there will be either an opening or a closing of the silver buttons. If the force on the armature is the greater, the buttons open, putting maximum

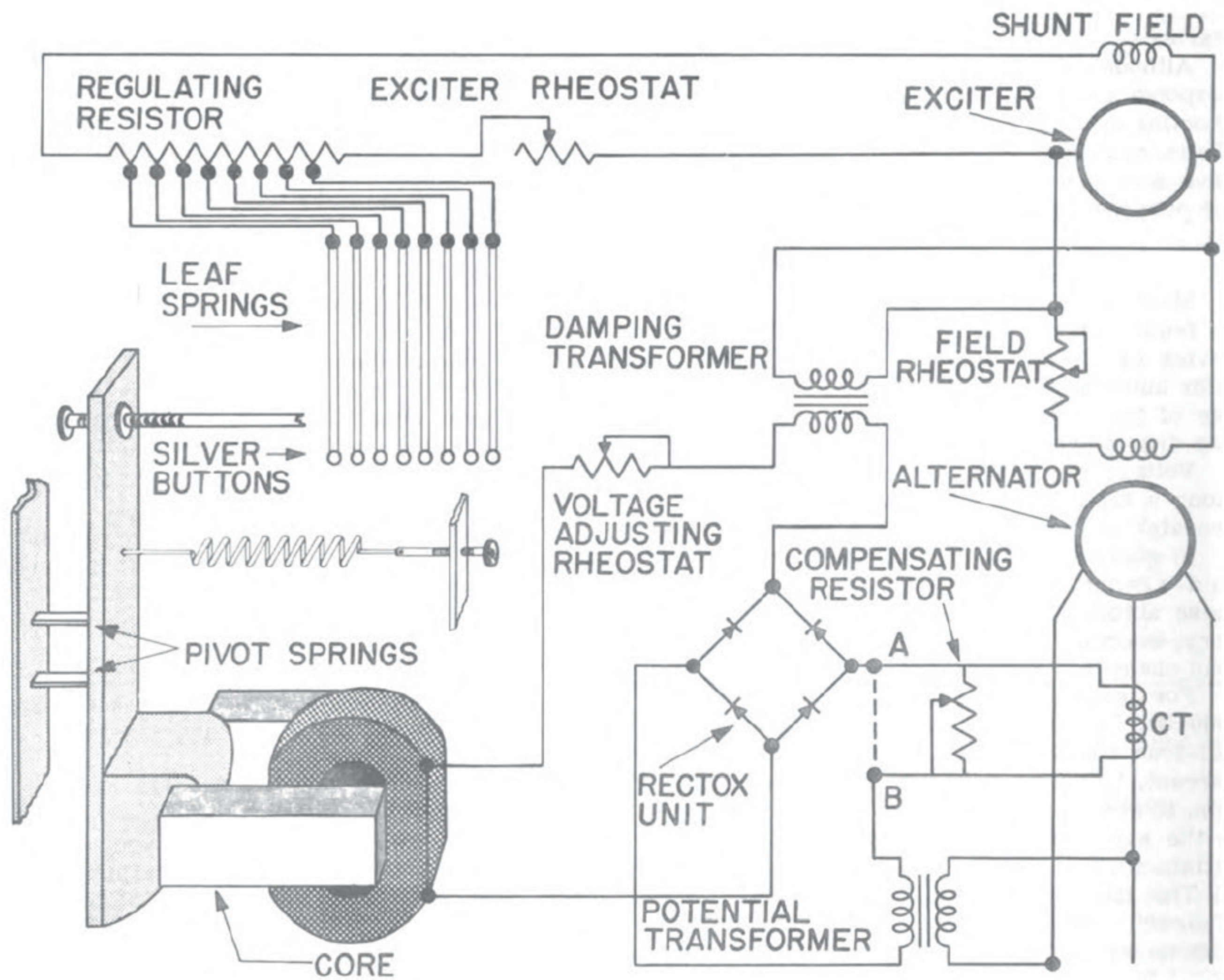


Figure 5-26.—Direct-acting voltage regulator.

resistance into the field circuit. If the tension of the coiled spring overcomes the magnetic pull on the armature, the buttons close, shorting out resistance in the field circuit.

These normally balanced forces vary when source voltage varies. If generator voltage rises, the pull on the armature increases, and this action puts added resistance into the exciter field. The added resistance operates to reduce the exciter field current, and consequently the armature voltage. The magnitude of this decrease is restricted by the action of the damping transformer.

When source voltage falls, the voltage regulator acts in the opposite fashion. The pull of the coiled spring closes the silver buttons, and shorts out resistance in the exciter field circuit. The damping transformer acts to restrict the magnitude of the resulting increase in exciter field current and armature voltage.

In figure 6-6, in the following chapter, you will find an illustration of the voltage regulator, and the voltage adjusting rheostat, mounted upon the control panel of a large generating unit.

Starters

Manual and automatic starters for motors are another type of controller device. Although commonly referred to as starters, especially in commercial use, these devices are classified as controllers in Navy specifications.

The MANUAL types are those in which the motor operator must set in motion the mechanical system by which the main contacts are operated. When these contacts are operated by an electromagnetic device, the starter is known as a magnetic controller.

Again, the magnetic controllers are divided into two types: SEMIAUTOMATIC, and AUTOMATIC. The semiautomatic type is a magnetic controller in which one or more manually operated switches govern the functions of the controller device. The functioning of an automatic controller, on the other hand, is wholly automatic, once the controller is energized. It may be initially energized by a pressure switch, a float control, a thermostat, or a similar device.

These magnetic controllers serve not only to start motors, but also to select and regulate speed, and to reverse the direction of rotation.

Controllers of the panel type must be kept dry and clean; there should be an easy access to the wires behind the board. Any unusual heat around these panels should be taken as an indication of electrical trouble, and an immediate inspection should be made to locate the trouble source. The common causes of excessive heat are loose contacts, or the use of leads that are too small for the currents carried.

The two principal uses of magnetic controllers are: (1) to cut out starting resistance, and (2) to cut out the accelerating devices as soon as the motor comes up to full speed.

Figure 5-27 is a diagram of a magnetic controller used to cut out starting resistance. As you can see, there are four positions for the starting arm: OFF, and positions 1, 2, and 3.

Close the line switch with the starting arm in the OFF position, and then move the arm to the first position. The shunt field is then connected across the line, the shunt coil is energized, and the contactor M_1 closes; with the field and armature excited, the motor starts.

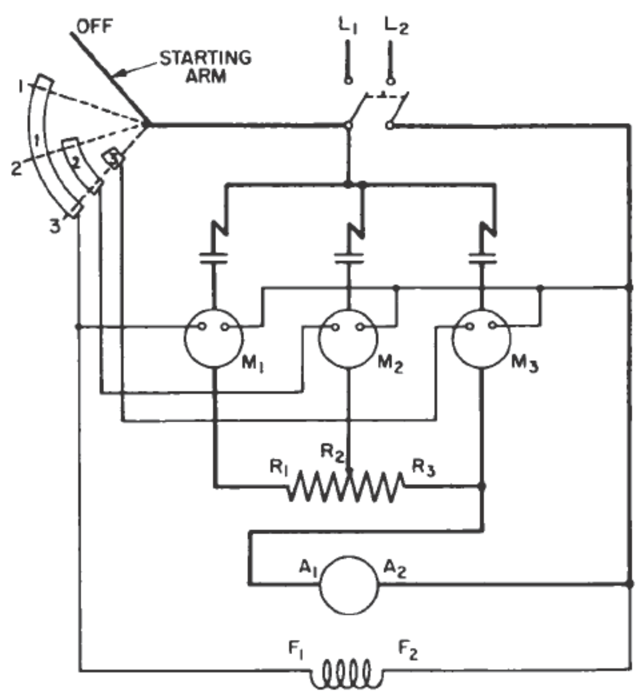


Figure 5-27.—Diagram of a semiautomatic magnetic controller, used to cut out starting resistance.

With the arm moved to the second position, the circuit is completed through the shunt coil of contactor M_2; the contactor closes, and resistances R_1 and R_2 are shunted out.

With the arm moved to the third position, the circuit through the shunt coil of M_3 is completed, and the entire starting resistance has been shunted out.

The fully automatic magnetic controller shown in figure 5-28 differs from the semiautomatic in that all the operator has to do is to close the line switch and press the start button.

CLOSE the LINE SWITCH and PRESS the START button. A circuit is completed from L_1 through the start button to shunt coils M and 1R to L_2. Notice that the current can't go through shunt coils 2R and 3R, because auxiliary contacts E and F are open. Contactors M and 1R are closed. (Auxiliary contact E is mechanically linked to contactor 1R, and contact F is linked to contactor 2R.) This completes a circuit from L_1 through contactor M, through the armature, through the resistance from R_3 to R_1, through the series relay coil C, and through contactor 1R to L_2. Also notice that the circuit through the shunt field is completed. The motor starts.

When accelerating contactor 1R closed, the contact E also closed. This would appear to complete the circuit through the shunt coil of 2R, but something else happens which prevents this. At starting, the motor draws a high current. This current flows through the series coil of relay C. The high current causes the relay to operate and the circuit to the shunt coil of contactor 2R is opened at point X.

However, as the motor speed increases and the counter emf builds up, the current is reduced. When the current is reduced to the correct value, the series relay drops back to its normal position and closes the circuit at point X.

There is now a circuit through shunt coil 2R. Contactor 2R closes, and a new circuit may be traced from L_1 through contactor M, the armature, resistance from R_3 to R_2 and contactor 2R to L_2. The resistance from R_1 to R_2 has been shunted.

The mechanically operated contact F is closed when contactor 2R is closed, but the control circuit through shunt coil 3R is not closed, because series relay B opens the circuit at Y.

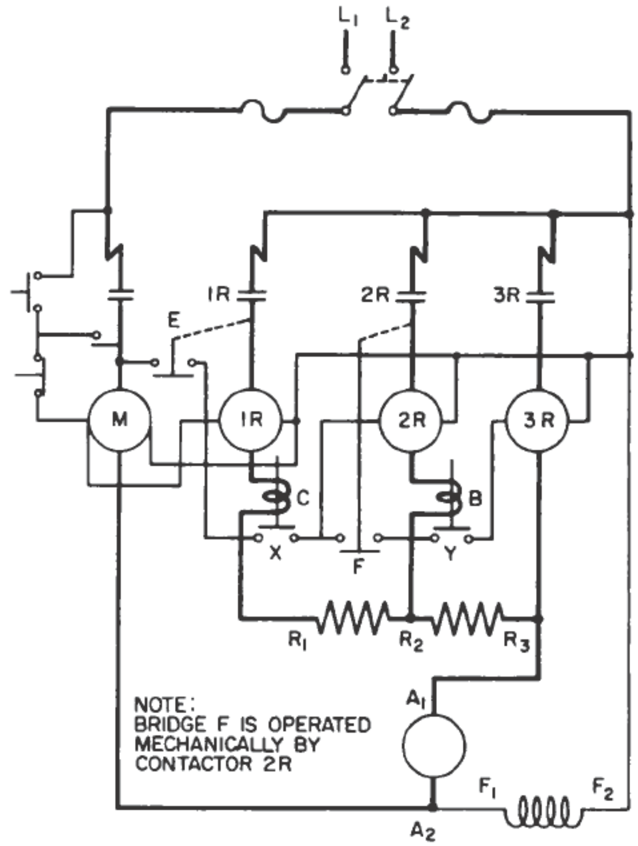


Figure 5-28.—Contactor panel for automatic reduction of starting resistance.

Remember—when contactor 2R closed, part of the armature resistance was shunted out. Therefore, the speed of the motor increases and the counter emf goes up, further reducing the armature current. This reduction in current permits the plunger of series relay B to drop to its normal position, completing the circuit through shunt coil 3R and closing contactor 3R. When contactor 3R closes, the entire starting resistance is shunted and the motor has reached its normal operating speed.

CARE OF INSTRUMENTS

The instruments that have been described in this chapter are of such practical use that they must be protected from any damage that would result in erratic or inaccurate readings. Replacements are not always available, and there is always delay when an instrument must be sent for shop overhaul or repair. Even

more hazardous is the possibility of the instrument being damaged without anyone being aware of the fact.

The accuracy of a-c instruments may be affected by a number of factors, both mechanical and electrical. Among the mechanical factors are: temperature, moisture, corrosion, dirt, vibration, shock, poor mechanical balance, and warping of the pointer or the scale. Electrical factors are: variations in voltage or frequency, variation in power factor, abnormal wave forms, electrostatic deflections, and overloads.

Remember that the information given in this chapter is to help you to use these instruments to better advantage, but not to help you to adjust or repair them. The case of an electrical measuring instrument, switchboard mounted or portable, must never be opened except by an experienced repairman. Nevertheless, you can do your part in seeing that these devices are given proper handling and maintenance.

Handling and Use

Remember that the coils of these measuring instruments are limited in current-carrying capacity, and can be instantaneously burned out by excessive current. As far as possible, deenergize a circuit into which they are to be placed, before you connect these instruments. Keep all contact surfaces clean, and keep the connections clean and tight.

In addition, keep the following points in mind; they are specific precautions that you should take to avoid burning out the coils:

1. Never use an instrument intended for d-c ONLY in an a-c circuit.
2. Never leave an instrument with its pointer deflected off scale, or in the wrong direction.
3. Never connect a d-c instrument to an instrument transformer.
4. Connect an ammeter or the current coil of a wattmeter or other instrument IN THE LINE, and never across the line. If you use an external shunt or current transformer, connect the shunt, or the primary of the current transformer, in the line.
5. Connect a voltmeter or the potential coil of a wattmeter or other instrument across the voltage to be measured. If you use an external multiplier, connect it in series with the voltmeter or potential coil. If you use a potential transformer, connect the voltmeter across the secondary of the potential transformer and connect the primary across the voltage to be measured.
6. Never open-circuit the secondary of a current transformer when the primary is energized.
7. Never short-circuit the secondary of a potential transformer when the primary is energized.
8. Ground one terminal of the secondary of each instrument transformer. Also ground the metal case enclosing the instrument transformer.
9. The coils of wattmeters, frequency meters, power-factor meters, and synchroscopes may carry an excessive current even with the pointer reading on scale. Hence, be careful when connecting these instruments to avoid excessive current in the coils since the pointer does not necessarily indicate an overload. Check the currents with ammeter readings before connecting the above-mentioned meters.
10. When using multiple-range test instruments to measure unknown values of voltage or current, always start with the highest range first and work down to a range that gives a deflection on the upper part of the scale.
11. Before applying voltage to the circuit, check to see that all connections are correct; otherwise the meter may be damaged or burned out.
12. Before taking resistance measurements, first disconnect batteries or other power to equipment under test and then discharge all capacitors. Do not test thermocouples, meters, or sensitive relays, which might be damaged by current from the ohmmeter. Use a special Wheatstone-bridge circuit for testing such devices.

Certain other precautions, of a general nature, should be learned and followed. For example, use instruments at a sufficient distance from generators, transformers, and conductors carrying large currents, so as to avoid errors caused by nearby magnetic fields.

Exposure to a strong magnetic field can magnetize the iron parts of moving-iron instruments, and impair the accuracy of the readings. Check the accuracy of any instrument if it has been exposed to a strong magnetic field, even though there is no visible sign of damage.

Never subject measuring instruments to mechanical shock by handling them carelessly. Avoid any pounding that could vibrate the switchboards upon which they are mounted, or

tables or benches upon which they have been placed.

Use the instruments in the positions for which they are calibrated. You will find that most portable devices are calibrated in the horizontal plane. Instruments mounted on switchboards are usually intended for installation in the vertical plane.

When using a voltmeter to measure a-c potential, connect the grounded line of the system (or the line low in potential with respect to ground) to the instrument terminal that is marked LO, or some similar sign. Connect the high potential line to the terminal marked HI, or some similar sign. This procedure ensures a minimum dielectric stress between the instrument circuits and the instrument case.

Disconnect portable voltmeters from field circuits, or other highly inductive circuits, before opening the circuit. Otherwise, you may find that the "inductive kick" is strong enough to bend the pointer.

After using a volt-ohm-milliammeter, do not leave it with the selector switch on the "ohm" setting. On those instruments where a small battery serves as a source of direct current, you can drain the battery by leaving the switch on ohm. It is safest to leave the selector switch on the highest voltage scale; this prevents damage if the instrument should inadvertently be connected to a voltage exceeding the lower range setting.

Never wipe the glass cover over an instrument pointer just before taking a reading. The friction may leave a small electrostatic charge on the glass, and this charge may attract the pointer. It is surprising what large errors may result from this electrostatic charge, in some types of instruments. If you must rub the glass before taking a reading, breathe lightly on the glass to dispel the charge.

When you are going to make an electrical test, be sure that you select the proper instrument. Make neat connections, that can easily be traced when the circuit must be checked. After you have the instrument and the circuit connected and ready for testing, it is a good idea to have a higher-rated man check the hook-up before you apply the voltage.

Although you are not supposed to open the enclosure or case of an electrical measuring instrument to make adjustments, there are certain minor adjustments that can be safely made by any experienced electrician.

Direct-current voltmeters and ammeters MUST be checked on direct current; alternating-current instruments should preferably be checked on an a-c standard, but if necessary can be checked on a d-c standard. However, do not attempt this unless you are quite sure that you understand the procedures.

For checking, connect a voltmeter and the standard to the same points on a source of variable voltage, taking comparative readings at a number of points on the scale. The ammeter is checked by connecting it in series with the standard.

You can easily check the accuracy of a frequency meter by comparing its reading with true frequency as determined from the number of poles and the speed of the a-c generator that is energizing the meter. Frequency is equal to the product of rpm and the number of field poles, divided by the factor 120. You will find a fuller explanation of this in chapter 6 of this training course.

In checking the accuracy of an ohmmeter or megger, remember that when the instrument is not in use there is no control over the moving element, and the pointer may stand at any reading. When the instrument is energized, the pointer should be at zero if the terminals are shorted, and at infinity if there is no resistance connected between the terminals. If the instrument reads correctly at zero and at infinity, it is reasonable to assume that it is accurate throughout. However, it is a wise precaution to make a check at intermediate points, by using resistance boxes, or a high-range d-c voltmeter or multiplier of known resistance.

Maintenance

Cleanliness is a primary factor in good maintenance. Keep the cases of instruments clean and dry. They should be stored in a place that is clean and dry, and that is protected against shock, vibration, strong magnetic fields, and extremes of temperature.

Lubrication should not be a problem inasmuch as the pivots and jewel bearings of electrical measuring instruments should NEVER be oiled. In the case of meggers, no provision is made for oiling from the outside of the case, since the assembly is intended for several years use, with no lubrication except that originally provided.

Any severe vibration or mechanical shock may easily damage jewels or pivots. If repairs that involve hammering, riveting, or drilling are to be made in the vicinity of a switchboard, remove and store the switchboard meters. Tag the leads so that the instruments may be reinstalled without error in connections.

QUIZ

1. How must a current-measuring instrument be connected with the line? With the load?

2. What 2 primary factors does the text list as placing limitations on the current rating of a multirange ammeter?

3. If you must connect an ammeter into a circuit carrying a current of unknown value, what range should you select?

4. Should voltage-measuring instruments be connected in series with the circuit to be tested, or in parallel?

5. If a voltmeter is connected in series with a circuit in which the voltage is within the meter range, which of the following will probably result?
   (a) Pointer will be immediately knocked off the dial.
   (b) Equipment on the load side may burn out.
   (c) Meter coil may draw a current so low as to give an inaccurate reading
   (d) None of the above

6. When fixed resistors are connected inside a voltmeter, how is the dial calibrated?

7. The instrument to be used for a true power measurement of an a-c circuit is the
   (a) ammeter
   (b) rectifier
   (c) voltammeter
   (d) wattmeter

8. What is the instrument used to indicate how much power is being wasted in a circuit?

9. What is the practical purpose of using a rectifier in a meter device?

10. The clamp-on voltammeter is used on an energized circuit for measuring
    (a) alternating current only
    (b) direct current only
    (c) direct current and d-c voltage
    (d) alternating current and a-c voltage

11. The general-purpose instrument commonly used for measuring both a-c and d-c current and voltage is the
    (a) frequency meter
    (b) megger
    (c) multimeter
    (d) voltammeter

12. The a-c power-circuit analyzer discussed in the text consists of a single case in which are mounted an ammeter, a voltmeter, a
    (a) wattmeter, and a power factor meter
    (b) wattmeter, and a voltammeter
    (c) megohmmeter, and a power factor meter
    (d) wattmeter, and a frequency meter

13. The purpose served by the rheostat in an ohmmeter circuit is to
    (a) act as a multiplier
    (b) ensure full-scale deflection of the indicator
    (c) compensate for decrease in battery capacity
    (d) extend the range of the meter

14. Which of the following measuring devices is usually powered by a small generator?
    (a) Circuit tester
    (b) Megger
    (c) Rectifier
    (d) Voltammeter

15. What is the general restriction on the range of a frequency meter?

16. Why are automatic voltage regulators necessary on a-c generators?

17. Semiautomatic types of motor controllers are those types in which one or more of the functions of the controller device are governed by
    (a) manually operated switches
    (b) thermostats
    (c) mechanical systems
    (d) pressure switches

18. If you connect a d-c meter to an a-c source, what will probably be the result?

19. Why should you avoid rubbing the glass-covered dial of an indicating instrument just before you take a reading?

20. How can you check the accuracy of a frequency meter?

CHAPTER 6

POWER DISTRIBUTION SYSTEM

The central point of a power distribution system is the generating station. For an advanced base, the generators must be rugged, to take the effects of rain, snow, or other climatic conditions. They must also be portable, to allow for any changes in location that may be made necessary by local conditions.

Advanced base generator sets are built as complete units, that include the prime mover and its necessary auxiliary equipment, and the switchboard. These units can be immediately located at the points where power is needed. However, it is advisable to establish a larger central distribution station as soon as possible. This ensures a steady supply of power to all points where it is needed; it affords the units protection from weather; and it makes possible some saving in manpower, since only one operator is required at a time.

The central power station usually includes two main generators and one emergency unit. In case of a breakdown, power distribution can be maintained by cutting the emergency unit onto the line.

Separate lines or feeders carry the voltage from the central station to the operational headquarters, the living areas, the supply center, the motor pool, the shops, and so forth. Distribution transformers will usually be needed, to step down or step up the voltage, to that required at the point of consumption.

If each feeder is made up of three wires, the distribution system is a 3-wire delta system, similar to the one shown in figure 6-1. If each feeder is made up of four wires, the system is a 4-wire grounded (or Star) system, such as the one illustrated in figure 6-2.

To understand what determines the type of distribution system, you must understand the construction of the main generators, and the arrangement of stator (or rotor) coils.

ELECTRICAL THEORY APPLIED TO GENERATING EQUIPMENT

Electrical generators convert mechanical energy to electrical energy. The basic principle of a generator is the same as that of a motor—namely, current will flow through a wire moved through a magnetic field, if the wire is in a closed circuit. Some generators operate on the principle of a rotating magnetic field, with a-c generated in the stator; but most generators operate on the principle of a wire rotated through a magnetic field.

As the wire is rotated at a uniform rate of speed through the magnetic field, it cuts across the magnetic lines of force and generates a voltage. When the wire is parallel to the flux lines, there is no voltage generated. When the wire is at right angles to the flux lines, maximum voltage is generated. There are two points at which no emf is produced; that is, there are two points where the wire is parallel to the magnetic lines of force. These two points are 180 degrees apart, and mark off 1/2 a revolution. As the wire moves into the second half of the revolution, it reverses voltage direction, and consequently reverses polarity.

The voltage generated depends upon the strength of the magnetic field, the number of turns of wire cutting the magnetic field, and the speed with which the wires are rotated. To produce the high voltages needed for practical applications, the field poles are made very powerful, the armature windings are made of a great number of turns of wire, and these coils are rotated at high speeds.

Generators that operate on this principle produce alternating current, since a-c can be defined as a current of regularly fluctuating voltage and a reversal of polarity at every half-cycle. Because of this reversal, some form of sliding contact must be used between the terminals of the coils and the external

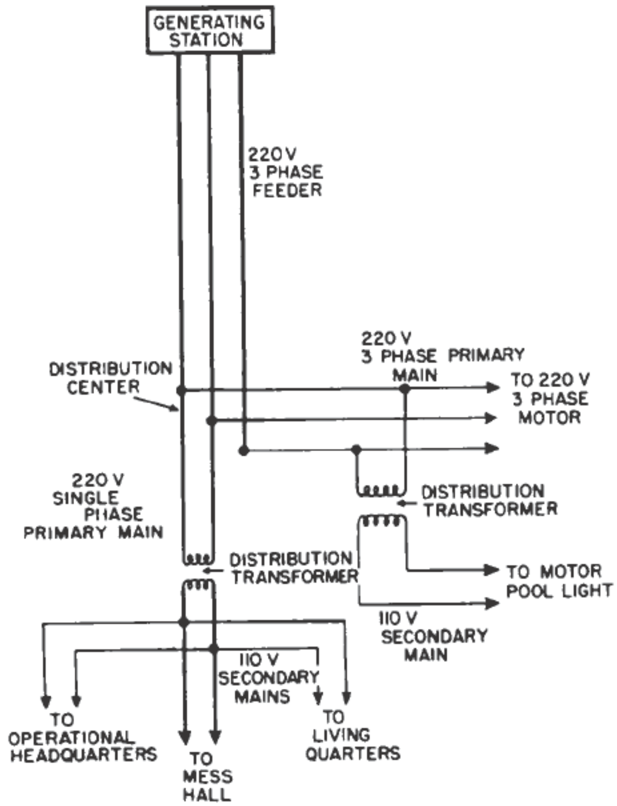


Figure 6-1.—A 3-wire distribution system.

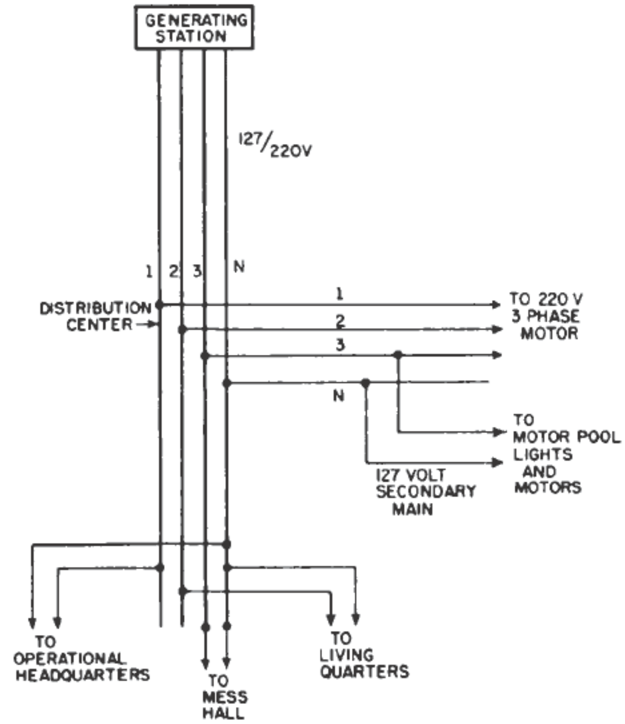


Figure 6-2.—A 4-wire distribution system.

circuit. The ends of the coils, therefore, are attached to slip rings mounted on the shaft; the external circuit is connected to brushes (carbon or copper), which rest on the rings and draw off the current.

Some generators deliver direct current. In these generators, the current generated is a-c, but is converted to d-c by means of a commutator. The way in which the current is RECTIFIED is as follows: the commutator, mounted on the shaft, is divided into equal segments. The number may be two or more, but we can take two as an example. Two brushes, directly opposite each other, each make contact with a segment; but as the coils rotate, each segment moves out of contact with one brush, and into contact with the other. By having the commutator segments change from one brush to another at the exact moment when the induced emf changes direction, it is possible to keep the current in the external circuit in one direction at all times.

There will be a certain amount of pulsation in such a d-c output, but this can be reduced by increasing the number of coils and the number of commutator segments and brushes. In this way, when one coil is generating zero or minimum voltage (the point at which pulsation occurs), the other coils are generating enough voltage to overcome the pulsation effect.

Alternating Current Generators

In most a-c generators, the field windings are placed on the rotor, or rotating part, and the armature windings are on the stator, or stationary part. You will remember that a similar description was given for a-c motors, in chapter 2 of this training course. In a design like this, the armature coils do not cut the magnetic field; but since the magnetic field is rotating, there is still a relative motion taking place between the armature coils and the flux lines, and inducing an emf.

Navy generators are almost entirely a-c generators, with frequency of 60 cycles. There may be some 25-cycle generators still in use, but there is not much likelihood that you will be called upon to operate one of these low frequency units. The rated rpm (revolutions

per minute) of any generator can be used to determine frequency, by means of the following formula:

$$\text{Frequency} = \frac{\text{number of field poles} \times \text{rpm}}{120}$$

TYPES of a-c generators are single phase and polyphase. The single-phase 2-wire or 3-wire generator is often used for lighting purposes. For power applications, the 3-phase generator is commonly used.

The 3-phase generator has three independent windings. Maximum voltage is not being generated in each winding at the same instant. The phasing depends upon the speed of rotation. If the generator frequency is 60 cycles per second, maximum voltage will occur 1/180 second apart.

An EXCITER is necessary to apply direct current to the rotor field windings, in order to provide a uniform magnetic field. This exciter may be separately driven, or it may be mounted on the shaft of the main generating unit. The magnetic field receives the direct current through slip rings.

PROTECTION against overload is not provided in the terminal leads of an a-c generator, except when the generator is small, and is operating as an isolated unit. When generators are operating in parallel, if a fuse or circuit breaker opened to protect one generator against overload, there would be the difficulty of resynchronizing the unit with the other generator in the system.

Even between generator and transformer, a protective device may be omitted if both these equipments are located in the same building, and are controlled and operated as a unit. However, in case of a short circuit in a transformer, an overload protective device between generator and transformer will prevent arcing in the transformer, and possible oil ignition.

Direct Current Generators

Even though the Navy uses a-c generators almost exclusively, it may be advisable for you to know something about the types and operation of d-c generators. It is possible that you may some day find yourself in a situation where you will have to depend upon a d-c generator for power.

TYPES of d-c generators are distinguished according to the type of windings on the field poles. Therefore, you will hear them referred to as series wound, shunt wound, or compound wound.

Series generators are good for loads that require a varying voltage and a constant power. As the load on this type of generator increases, the increase in field current strengthens the magnetic field, and thus increases voltage.

In shunt generators, field current is almost constant; as a result, the magnetic field and the generated voltage are constant. However, if the load is increased, there is a reduction of armature voltage, and a reduction in terminal voltage. This brings about a decrease in field current, and in turn, a further drop in terminal voltage.

Compound generators have a series field added to a shunt generator, to compensate for voltage drop in the shunt generator when load is increased. This type has the advantage of holding terminal voltage almost constant. Some compound generators have a switch which can be opened to short circuit the series field, and allow for operation as a simple shunt generator.

When the required load exceeds that of a single generator, two compound generators can be connected in parallel. An equalizer line is necessary in order to divide the load equally between two d-c generators. The equalizer connections are made at the armature terminals, so that the SERIES fields are connected in parallel. In this way, you ensure that current from the generator having the largest load will flow in part through the series field of the other generator; the effect of this is to raise the voltage of the second generator, and so rebalance the load.

An EXCITER is necessary to supply current to the field windings, when the generator is started. D-c generators may be separately excited, or self-excited. In the former case, a battery supplies current for the field windings. The self-excited type is one in which the generator itself supplies this current. The prime mover starts the generator; as the armature begins to revolve, it generates a small voltage, which is impressed across the field windings, causing a small field current to flow. This current increases the magnetic field. Thus the generator gradually builds up a normal magnetic field between the field poles, until the armature is generating rated voltage.

When a self-excited generator is to be closed down, load resistance in the line circuit should be reduced to zero, and the generator slowed down by cutting out the prime

mover. If the generator shuts down by accident, or for any other reason, while the load resistance is high, it is possible that the residual magnetism (the magnetism that remains in the poles after the emf has been removed) of the field poles may be reversed; then, when the generator is started up again, voltage polarity is also reversed. This situation can be remedied by exciting the field poles with a battery, until the correct residual magnetism has been reestablished.

PROTECTION may have to be provided, on a d-c generator, against short-circuit overloads, which could burn out the armature. Use a circuit breaker for this purpose. On a low voltage generator (65 v or less), driven by an individual motor, no separate protection is needed if the motor protection device will operate as soon as the load being delivered becomes as high as 150 percent of full load rated current.

INSTALLING THE CENTRAL POWER STATION

When installing the generators in a power station, give careful attention to three factors: vibration, ventilation, and grounding.

Vibration must be kept to a minimum. The foundation for the generator will have to be level and rigid. A flexible coupling used between prime mover and generator will help to reduce the transmission of motion. If there is time to have a concrete deck constructed, this is the preferable foundation. Failing this, have a wooden platform built. Make sure that the plant is leveled on its platform or deck.

The location should be dry and well-ventilated, to protect the insulation against deterioration. Make sure that there is room enough so that maintenance can be easily and safely performed.

The frame of the generator should be grounded if the terminal voltage is over 150 volts. The grounding system for a generator station should have (IF POSSIBLE) a resistance to ground of less than 1 ohm. Where the frame is not grounded, it must be insulated from the ground. No live parts of the unit should be left exposed.

The voltage output from the generators is controlled at the switchboard. It is first delivered to the bus bars, then distributed to the feeder lines.

All of this system should be carefully inspected after the plant is installed, and before it is put into operation. A visual inspection should indicate whether there are loose or broken electrical connections, or loose bolts or screws. If there is a question about any wiring connection, it should be checked against the wiring diagrams that are shown in the instruction manuals that accompany the power units.

The following checks, made before the plant is put into operation, may save time and trouble:

1. Check all electrical connections, to make sure that they agree with the plant diagrams.
2. See that collector rings are clean and polished.
3. Check brushes for location and for any tendency to stick in the brush holders.
4. Check brush pressure to see that it agrees with the pressure recommended in the operation manual; if no specific pressure has been recommended, use a pressure of 2 psi.

Connections

In most cases, the generators that supply power to the feeder lines are of the 3-phase type. The three stator coils, set on the stator core, are 120 electrical degrees apart. The output of these coils is connected through oil switches to the switchboard, and from the switchboard and bus bar to the feeder lines. The arrangement of the stator coils, therefore, determines the number of wires in the feeders.

If the stator coils are arranged in a delta connection, as illustrated in figure 6-3, the voltage is taken off via lines connected to each corner of the delta stator. If the stator coils are connected by a Y (or Star) connection, you can get four output wires from the three stator coils.

In figure 6-3, any of 2 of the 3 lines leading from the generator stator to the switchboard is across the ends of one of the coils; that is, lines 1 and 2 are across the two ends of coil A, lines 2 and 3 are across the two ends of coil B, and lines 1 and 3 are across the two ends of coil C.

Since this is a 220-volt generator, a voltmeter reading between any two of these lines across the ends of a coil would indicate the single-phase voltage (in this case 220 volts) developed in that coil. You can obtain a 3-phase voltage by taking the output from all three leads at the same time.

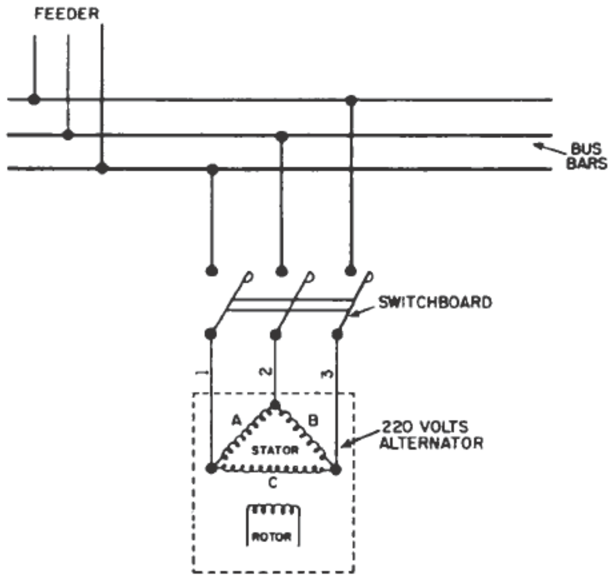


Figure 6-3.—Delta-connected generator.

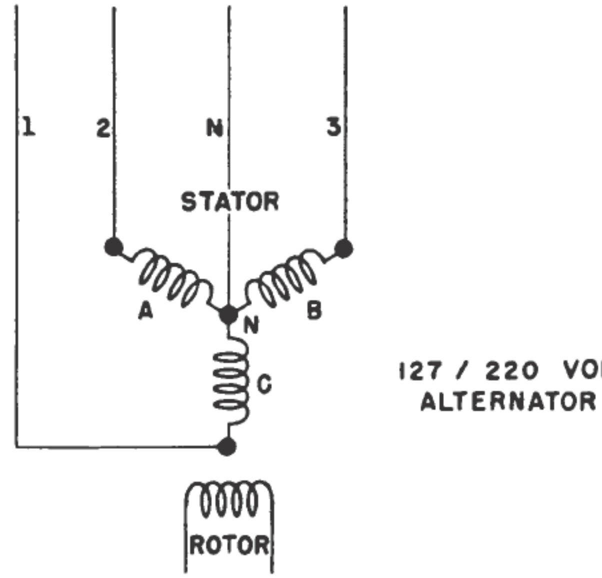


Figure 6-4.—Y-connected generator.

Notice that in the Y-connection shown in figure 6-4, one end of each coil is connected to the neutral wire, identified in the figure by the letter N. The other end of each coil is connected to one of the hot lines. The two lines numbered 1 and 2 are connected across two coils, A and C. Lines 1 and 3 are connected across the two coils, B and C. Lines 2 and 3 are connected across the two coils A and B.

This is different from the delta connection, where any two lines are connected across only one coil, and where the voltage between the lines is the rated voltage of the generator. With a Y-connection, the voltage between any two live lines is the vector sum of the voltages developed in the two coils across which the coils are connected.

On the other hand, the voltage between any hot line and the neutral line is the rated voltage of the generator, since the neutral line and any hot line are connected across a single coil. For example, a voltmeter placed between line 1 and the neutral wire would indicate the voltage developed in coil C; but a voltmeter placed between line 1 and line 2 would indicate the voltages developed in coils A and C.

A Y-connected generator, therefore, has two voltage ratings: the voltage developed across each stator coil, and the voltage developed across any two stator coils. The first voltage will be the rated voltage of the generator, and the second voltage will be roughly 1.7 times the first voltage. Mathematically, the second voltage is the first voltage multiplied by the square root of 3; the value 1.7 is close enough for all practical work.

Phase Sequence

You have already learned that in a 3-phase generator, the coils are equally spaced about the armature, and are 120 electrical degrees apart. Similarly, in a polyphase generator having 2-phase power, or 6-phase power, the coils are spaced at 180 degrees, or at 60 degrees. The number of electrical degrees between coils depends upon the number of coils. The 3-phase generator is the one most widely used for power production, but a 6-phase generator may be used to operate a large rectifier.

Since maximum voltage occurs in each coil at a different time, the ends of the various coils should be identified where they are brought out to the terminals. If they are not marked at the terminals, phase sequence must be determined in some other manner.

A simple phase-sequence indicator can be made by using two lamps and a highly reactive coil, such as the potential coil of a watt-hour meter. The method of connecting them is shown in figure 6-5.

If lamp No. 1 is bright, the phase sequence is A, B, and C. If lamp No. 2 is bright, the phase sequence is C, B, and A.

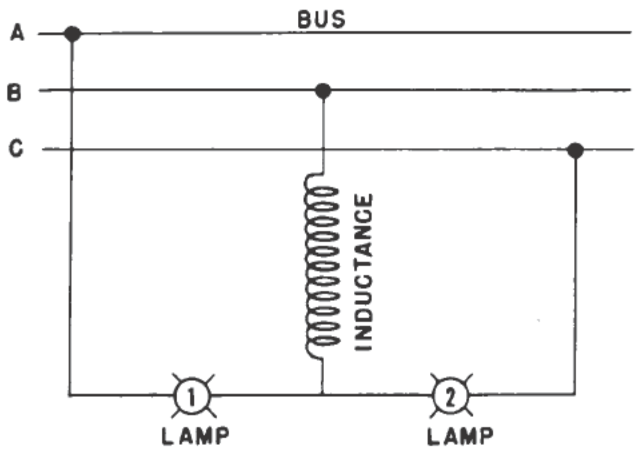


Figure 6-5.—Phase-sequence indicator.

Another method of determining phase sequence is to use a voltage tester equipped with three, instead of two, leads. The instrument is marked to show the relation between the voltmeter reading and phase sequence. Two of the leads are used to measure the voltage across two phases, and the third lead is then touched to the other phase. One order of phase sequence is shown by a sharp increase in the voltmeter reading; the reverse sequence is shown by a sharp decrease in the voltmeter reading.

SWITCHBOARD AND DISTRIBUTION PANELS

Every generating set at an advanced base must have a control panel. The size of this panel, and the number and type of controls that will be mounted on it, will always depend upon the size of the central power station and upon the type of electrical equipment to which the station must supply power.

A generator unit must be set up immediately when an advanced base is first occupied, in order to provide the power required for the temporary lighting system, the pumps, the communications system, and other services that are basic to the building of the base itself.

If the base is to be made a permanent one, a central power station must be established, for control and distribution of electric power to all spaces and services throughout the base.

The panel or switchboard used for the single portable unit first set up is called a switchboard, and all the necessary meters, switches, and other devices are mounted upon it. The control panel for a central power station is a combination of two switchboards, one for each of the main generator units, and a third panel that contains the switching equipment. This switchboard assembly is know as switchgear.

Figure 6-6 is the type of panel that you will find when a single generator unit is set up in the early days of an advanced base. Figure 6-7 shows the switchboard of a single generator in a central power station. Figure 6-8 shows the switchgear unit for a central power station containing two diesel-electric plants. A study of these three illustrations will show you that there is considerable difference between the instruments mounted on the panel in figure 6-6, and those mounted on the panel in figure 6-7. You can also see that the last two sections of figure 6-8 are identical with the panel shown in figure 6-7; the first section carries meters and switches common to both generator units.

There are 18 devices identified on the control panel shown in figure 6-6. Six of these devices have to do with the prime mover. Installing, operating, and maintaining prime movers are not duties of the Construction Electrician rating, but you should understand the purposes of these devices when they are mounted on the generator switchboard.

The THROTTLE controls fuel feed to the engine cylinders, and therefore controls engine speed. If the generator units are equipped with a governor, the latter acts as an automatic throttle, maintaining a constant engine speed, and a constant frequency output of the generator.

The OIL PRESSURE GAGE gives the reading of the oil pressure in the engine (normally about 30 psi).

The AIR-HEATER SWITCH starts the heater unit for preheating the air to the cylinders. This air heater unit is used only for cold-weather starting, and is turned off after the engine has been started.

The AIR-HEATER PUMP is used to pump oil through the spray nozzle of the air heater unit, and this oil spray is then ignited by the air-heater ignition system.

The WATER TEMPERATURE GAGE records the temperature of the water in the engine cooling system. The range from 160 to 185 F represents the normal temperature range of the water.

The ELAPSED TIME METER indicates the number of consecutive hours that the engine has been in operation, and is a guide to whether

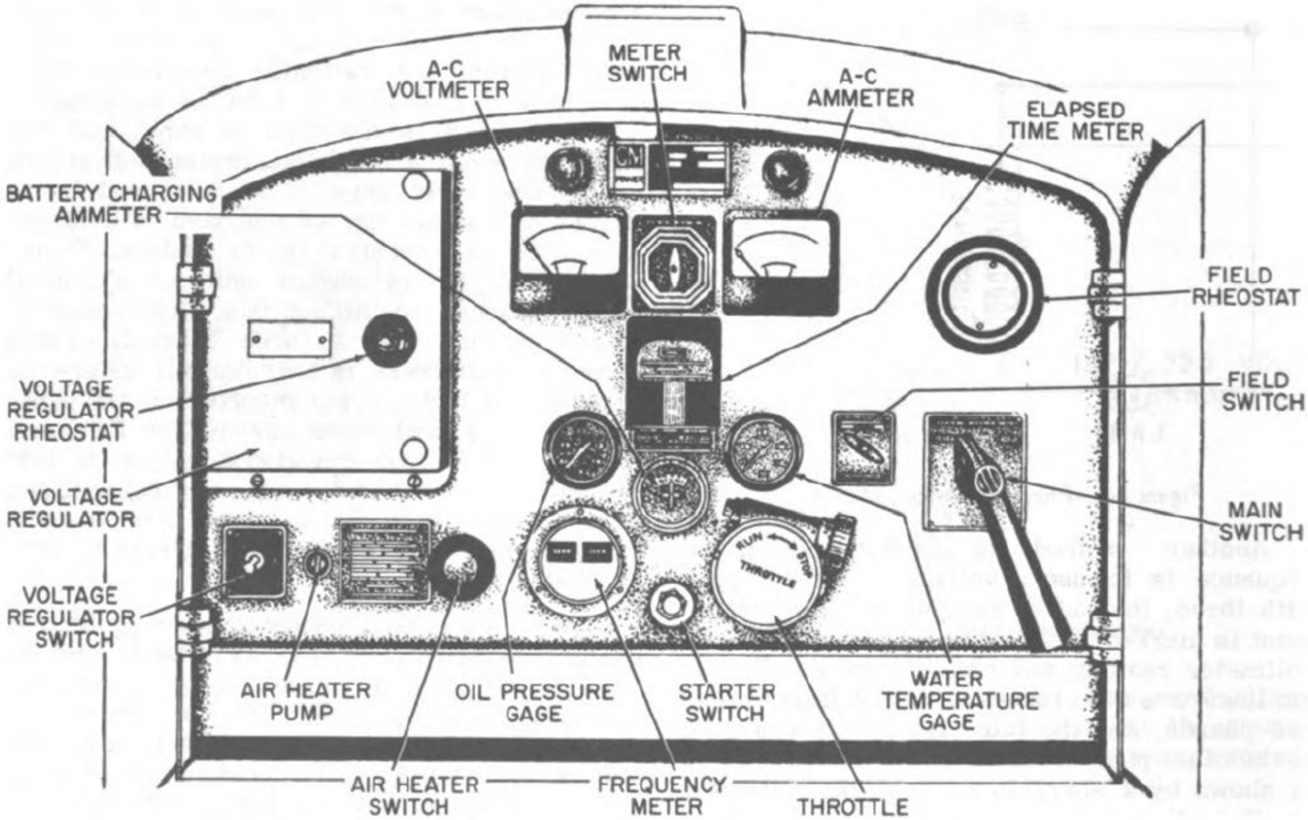


Figure 6-6.—Control panel for a large diesel-driven generator unit.

or not the engine needs lubrication or any other form of preventive maintenance.

The STARTER SWITCH is pushed in to close the circuit between the battery and the starting motor.

The BATTERY-CHARGING AMMETER records the amount of current delivered to the battery by the charging generator, and the amount of current that the battery itself is delivering on discharge.

The FIELD SWITCH is used for controlling the output of the exciter. Putting the switch in the ON position makes the necessary connection between the exciter field and the exciter armature. The switch should be thrown to the OFF position before the prime mover is stopped. This not only disconnects the exciter field, but also shunts a field-discharge resistor across the exciter field coils, to absorb any high voltages that might result from the quick opening of the field circuit.

The FIELD RHEOSTAT is in series with the exciter field; it can be adjusted to increase or decrease the voltage output of the generator. The effect of the rheostat upon generator output comes about through the following steps: the rheostat controls the voltage output of the exciter; the value of exciter output determines the amount of exciter current flowing in the generator field coils; and the amount of exciter current in the field coils controls the voltage output of the generator.

The VOLTAGE REGULATOR also serves to control generator voltage output. The use of this device makes it unnecessary to change the field rheostat setting when the generator output voltage varies from normal. How the voltage regulator serves to keep generator voltage at a constant value has already been explained in the preceding chapter, Meters and Controls.

The VOLTAGE-REGULATOR SWITCH is put in the ON position to activate the voltage-regulator unit. With the switch in the OFF position, any adjustment of generator output voltage must be made by means of the field rheostat.

The VOLTAGE-REGULATOR RHEOSTAT is a small variable resistor mounted on the voltage regulator unit. The setting of this rheostat

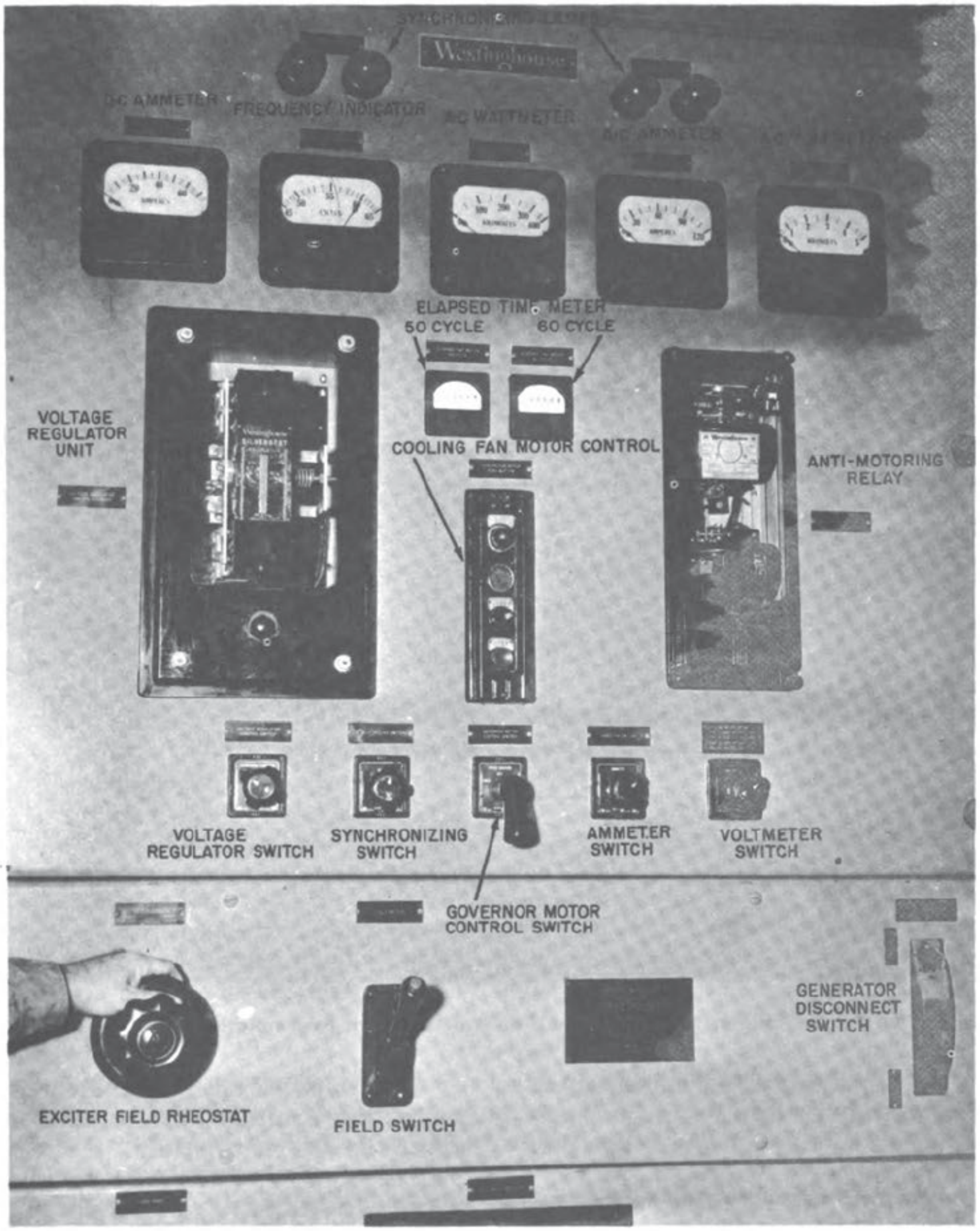


Figure 6-7.—Single switchboard, part of a switchgear unit.

does not keep the generator output voltage at a constant value (since this is the function of the voltage regulator), but it does determine the VALUE at which the voltage will be held constant.

The A-C VOLTMETER gives you the reading for the voltage output of your generator unit. Watch this meter as you adjust the field rheostat, or the voltage regulator rheostat, since it tells you when you have reached the rated voltage output of the generator.

The A-C AMMETER reading shows the current output of the generator. During operation, you should check the ammeter reading to determine whether there is any overload or unbalancing of a line.

The METER SWITCH is a necessity for the operation of a 3-phase generator. Each position of the switch puts the voltmeter and the ammeter in a different leg of the 3-phase line, so that it is possible to reach the voltage

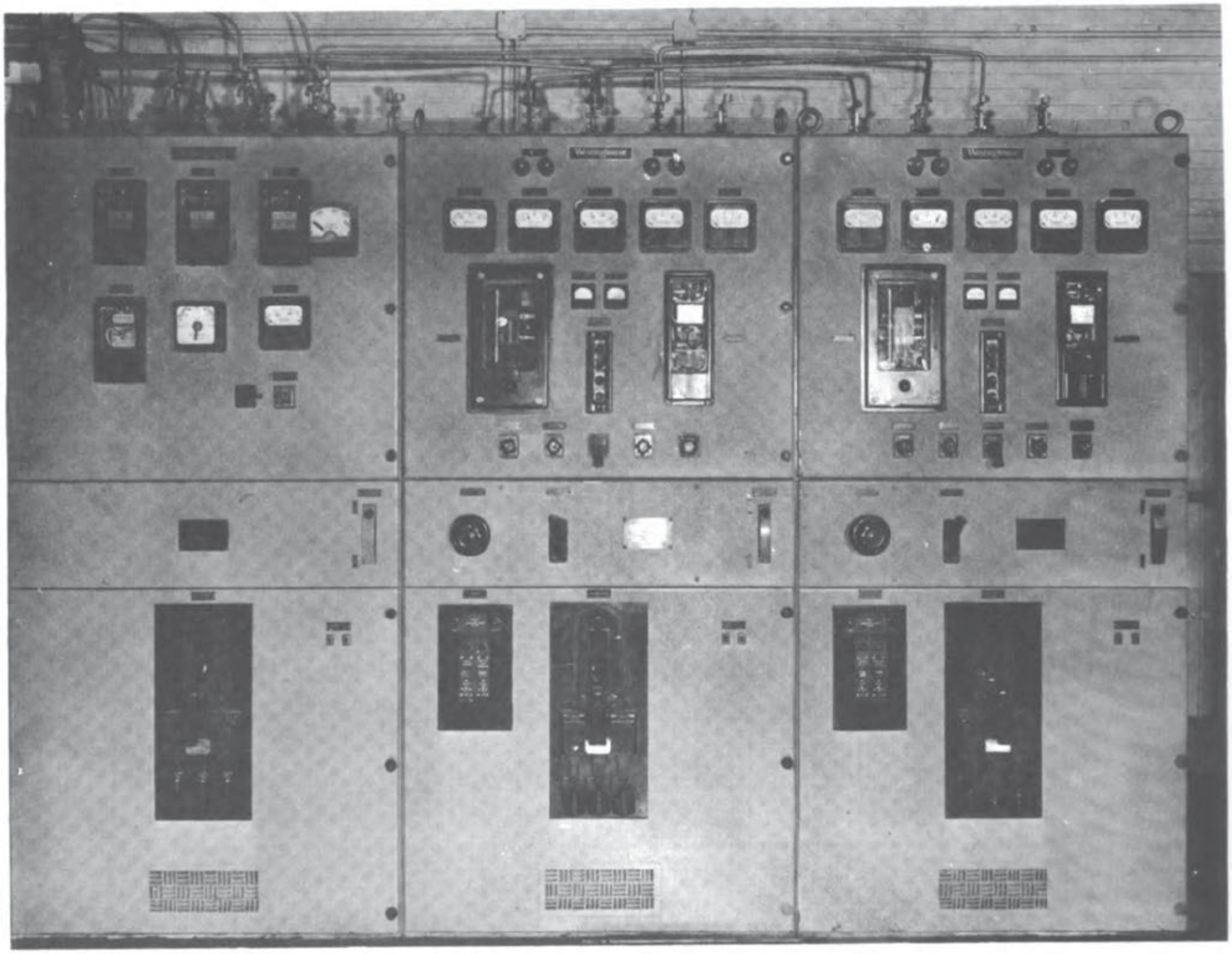


Figure 6-8.—Switchgear unit for a control power station.

across any two legs, and the current in any one leg. When the switch is thrown to the OFF position, the ammeter and the voltmeter are completely disconnected.

The FREQUENCY METER shows the frequency, in cycles per second, of the generated voltage.

The MAIN switch opens or closes the circuit between generator and load, but does not shut off the generator. Most main switches have a built-in circuit breaker, which automatically opens the main switch whenever the circuit between generator and load carries a continuous overload current.

On the panel shown in figure 6-7, there are several meters and switches not shown on the panel in figure 6-6. Let us consider them in order, beginning with the top left-hand meter.

The D-C AMMETER indicates current output of the exciter. This output becomes the input to the alternator field.

The A-C WATTMETER indicates the power output, in kilowatts, of all three phases of the power plant.

The COOLING FAN MOTOR CONTROL is a pushbutton switch which is operated to start or stop the cooling fan mounted on a radiator unit outside the central power station building.

The GOVERNOR MOTOR CONTROL SWITCH permits remote control of the governor speed setting of the prime mover.

The ANTI-MOTORING RELAY opens the main circuit breaker should the generator begin to operate as a motor (as it will if power flow is reversed). This reverse power flow can occur

if the governor of the prime mover holds too low an engine speed for two generators operating in parallel.

The SYNCHRONIZING SWITCH cuts the synchronizing lamps (at the top of the switchboard) into the circuit, when the two generators are paralleled. The way in which the lamps are used to check the synchronizing of the generator units is described in chapter 7, Operation of Generating Equipment.,

The AMMETER SWITCH is a 3-position switch which connects the a-c ammeter into each phase line of the generator in turn. This makes it possible for the operator to read the current of each phase line from a single meter.

The VOLTMETER SWITCH is a 4-position switch which connects the a-c voltmeter across each phase of the generator.

The GENERATOR DISCONNECT SWITCH is an interlock safety switch which must be operated before the main switch can be closed or opened.

All of these meters, switches, and controls that are mounted on the face of a switchboard or a switchgear unit are controlled by, or control, other equipment located behind the switchboard. For example, the output cables from the generator are brought to the back of the switchgear, and connected to the input terminals of the main switch. The output terminals of the main switch are connected to the bus bars. These latter serve as a point for the collection and the distribution of all the power generated at the central power station, and used at the numerous points of consumption.

Instrument Transformers

The voltages and currents delivered at the bus bars of a switchboard would be much too high for safe operation of the switchboard apparatus. Instrument transformers, therefore, are mounted on the back of the switchboard, and connected to the bus bars; they step down the voltages and the currents fed to the meters and relays, and to the voltage regulator. By the use of these instrument transformers, switchboard apparatus can be insulated from the high voltage circuit, and yet indicate accurately the voltage, current, and power in that high voltage circuit.

If these various devices mounted on a switchgear unit were powered by the high voltages fed to the switchboard, they would have to be individually grounded, not only to allow for safe operation by personnel, but also because the instrument would become inaccurate when connected to a high voltage. These inaccuracies are the result of electrostatic forces acting upon the indicating elements.

The transformers used to reduce large current values to the small current necessary for the operation of ammeters, and of the current coils of other instruments, are known as CURRENT TRANSFORMERS.

Those transformers which serve to reduce high voltages to small proportional voltage values, sufficient for the operation of voltmeters, and of the potential coils of other meters, relays, and instruments, are known as POTENTIAL or VOLTAGE TRANSFORMERS.

The design and operating principles of instrument transformers are described in chapter 16 of *Basic Electricity*, NavPers 10086, so that only a few words of explanation should be necessary in this training course.

The primary winding of a current transformer may consist of a few turns around a laminated iron core; it may, in some cases, consist of the bus bar or the cable carrying the line current. Some current transformers have an open window in the case, and turns in the line conductor can be made through this window. Thus, the primary is always connected with the line carrying the current.

The secondary winding consists of several turns of relatively small wire, wound around a laminated core. It is the secondary, of course, that is connected to the current coils of the instruments, or to the ammeter. The current rating of the secondary is almost always 5 amp, regardless of the current rating of the primary.

The secondary should never be open-circuited while the primary is energized. An open-circuited current transformer might develop several thousand volts across the secondary, where there would be only a few millivolts when the circuit is closed. This high voltage could break down insulation, and ruin the transformer, as well as cause severe and even deadly shock to the operator.

Once you realize that the current through the primary of a current transformer is determined by the load on the system, and that the load may vary widely, you will understand the need for safety precautions. For protection of both the operator and the equipment, a necessary rule is: NEVER OPEN THE SECONDARY

OF A CURRENT TRANSFORMER WHEN IT IS CONNECTED IN THE CIRCUIT.

Potential transformers have a low power rating. The low side of the transformer is usually wound for 110 volts, and the ratio of turns is determined by the rating of the high voltage side.

The primary is connected across the voltage source to be measured, and the secondary is connected to the meter or other indicating device. The current through the voltage transformer depends upon the burden imposed by the load on the meter or other measuring device. This load is always constant.

The secondary should always be grounded at one terminal, to eliminate static from the measuring instrument, and also to protect personnel. The important safety precaution to remember here is: NEVER SHORT-CIRCUIT THE SECONDARY OF A POTENTIAL TRANSFORMER.

Bus Bars

The bus bars through which the power generated at the station is distributed, are insulated copper straps. Where a modern metal-clad switchgear assembly is part of the power equipment, these bars extend from one switchgear unit to the next.

The surface of each tap is silvered, for low resistance, and every tap is enclosed in a box filled with an insulating compound. A ground bus extends throughout the switchboard assembly. Access to the main bus is provided at the rear of the switchgear unit.

Controls

Various controls are shown on the panels in figures 6-7 and 6-8, but there has been no mention of surge protection, or of any control for feeder circuits.

If your central power station has the newer type of metal-clad switchgear, there will probably be one unit in the assembly that will provide especially for surge protection. This unit will contain a set of main bus bars, capacitors, lightning arresters, and a potential transformer from the bus potential voltmeter.

There will also be a feeder circuit unit from which the power is sent out over feeder wires, to the points of consumption. This unit contains a set of main bus bars, a feeder circuit breaker, instrument transformers, and the necessary switches, meters, and relays.

Grounding

The metal cabinet in which each power panel is mounted, and the neutral bus in the switchgear unit, must be grounded. However, there are many metal parts of the power distribution system which do not normally carry electric current, and they require grounding, also. It is usual, therefore, to establish a grounding plan, or system, that will take care of all metal parts such as the bases and frames of motors and generators, the steel tanks of distribution transformers, switchgear apparatus, and any other metal parts that might permit the development of an electrostatic field.

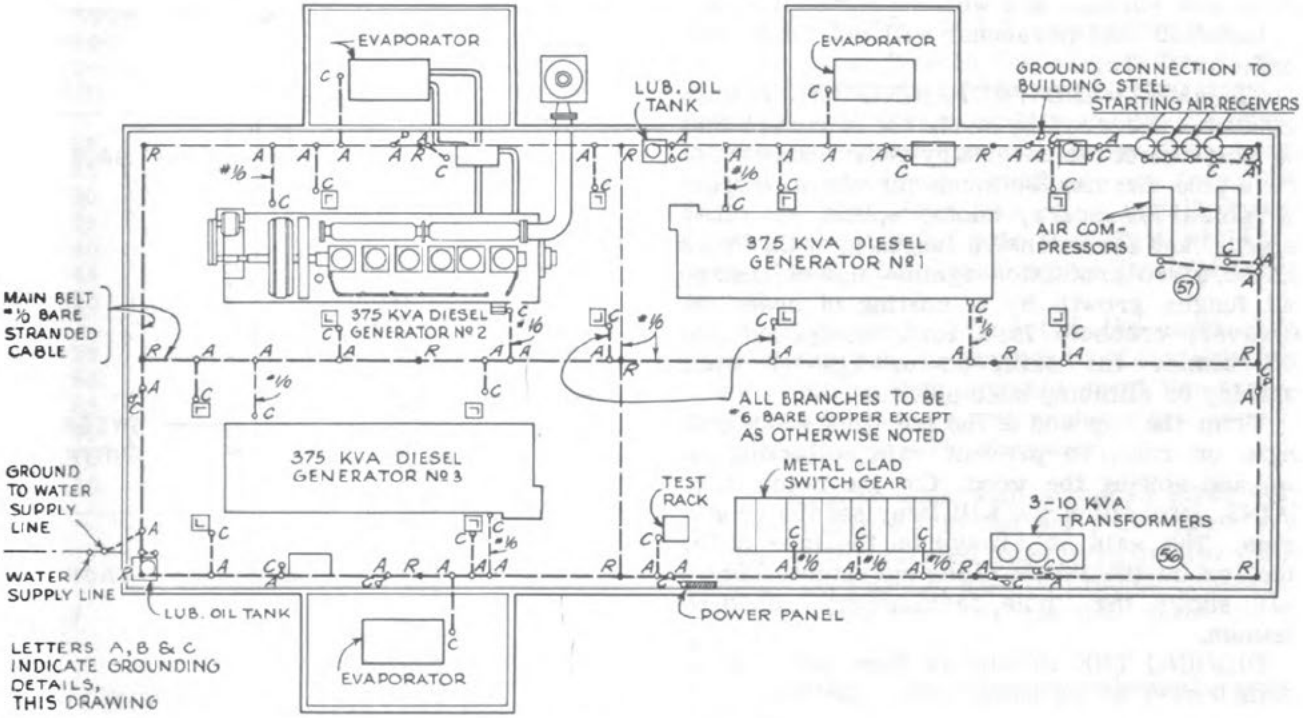
The usual method is to install the preliminary features of the grounding system during the early stages of base construction. Cables must be laid, and ground rods driven, before concrete decks and foundations are poured. The cables are left slack along the prescribed routes. Provision is made for connecting the branch cables that will lead to the individual pieces of equipment.

Figure 6-9 shows a typical grounding plan. The dotted lines represent the route of the grounding cables; the letter R is used to denote where grounding rods should be driven; the letter A indicates those points at which branch cables will be connected; and the letter C indicates the points at which branch cables will be connected to equipment. Bare stranded copper cable is used throughout the grounding system, with No. 0 size used for the main belt, and for the branch cables.

When the power plant has been installed, the branch cables are connected at one end to the equipment, and at the other end to the main belt of copper cable encircling the station. This main cable is grounded to earth at frequent intervals throughout its run.

CABLE INSTALLATIONS

Power from the generating plant at an advanced base may be carried to the various points of consumption by overhead transmission and distribution lines, by underground



PLAN OF GROUNDING SYSTEM

SCALE 1/8"=1'-0"

Figure 6-9.—Typical grounding plan for an advanced base power plant.

cables, or by a combination of both. At most advanced bases, you will find the high voltage developed at the central power station is usually distributed by means of overhead feeder lines. Such lines are cheaper to build, simpler to inspect, and easier to maintain than underground cables; but the latter may be necessary where power must be distributed to isolated areas, or where an overhead system cannot provide continuous service. An underground system is also a factor in preventing hazardous conditions at airfields and at material-handling areas.

Overhead Systems

In general, the different stages in stringing the overhead system are: trimming and preparing the poles; digging the holes; erecting the poles; facing the poles; guying, mounting the crossarms, and stringing the conductors; and adjusting for tension and sag.

When a base is first being built, trees may be used as poles for overhead wires. However, when the base is being readied for permanent occupation, regular wooden poles will have to be substituted. This changeover will include digging holes and providing supports for the poles. It will probably also include laying out new routes over which to string the wires, since it is unlikely that the original use of available trees followed the best route for the distribution system.

In planning an overhead system, arrange the route with the possibility of future development in mind; that is, make it possible to add additional circuits for new buildings and equipment. Consider also the nearness of other electrical circuits or pole lines; and be careful, also, not to place electric light and power wires on the same crossarms with telephone, telegraph, and signal wires.

If you run wires on the sides or roof of a building, to save the cost of installing poles, you must make sure that these wires will

carry low voltage, are well supported, and are so installed that personnel will not come into contact with them.

TRIMMING AND PREPARING THE POLES should be preceded by a check, to ensure that the poles meet the necessary standards. Do not use a pole that has too much curvature. Inspect the poles for scars, knots, splits, or other defects, and for extensive fungus growth. Poles can be given protection against insect damage and fungus growth by a coating of creosote. However, creosote is a toxic compound that will blister the skin, so use gloves when handling or climbing such poles.

Trim the top end of the pole to a 45-degree angle or roof, to prevent rain collecting on top, and rotting the wood. Cut the notches, or GAINS, into which you will later set the cross-arms. The gain is always on the face of the pole, or on the inside of the curvature. Figure 6-10 shows the "pole terminology" used by linemen.

DIGGING THE HOLES is done either by an earth borer, or by hand tools. The hole must be slightly larger than the butt of the pole, and the soil should be placed to one side as it is removed, and then later it is used for tamping.

The distance between the poles depends chiefly upon the nature of the terrain. The depth of hole depends on the length of the pole, and the holding power of the earth. Table 6-1 furnishes a guide to the depth to which holes should be dug.

Where hand tools, rather than a power borer, are used for digging, start with a short-handled shovel, and then change to a long-handled shovel as you get down to a depth of several feet. If the soil is so dry that it will not stick to the shovel, use a digging spoon instead. If the ground is of hard clay, or is rocky or frozen, loosen it first with a digging bar.

ERECTING THE POLES is done by means of pikes, or of mechanical devices such as the jenny or the boom. Whatever the means used, raising the pole should be done with caution. Every man should keep his mind on the job, and should make changes in his position only when ordered to do so by the man in charge of the crew. The men who are using pikes should be sure, before the operation begins, that their footing is secure. Figure 6-11 illustrates a crew raising a pole.

The jenny is a wooden support in the form of an X; it furnishes a support for the pole when the pikemen change from higher to lower position. Another device used for the same purpose is the deadman, or mule. This device is a long wooden rod with a metal spike at one end, for anchoring it in the ground, and an iron fork or curve at the other end, for holding the pole.

The pike poles add extra lengths to the crewmen's reach. The pikers are paired along the upper end of the pole, and push upward and

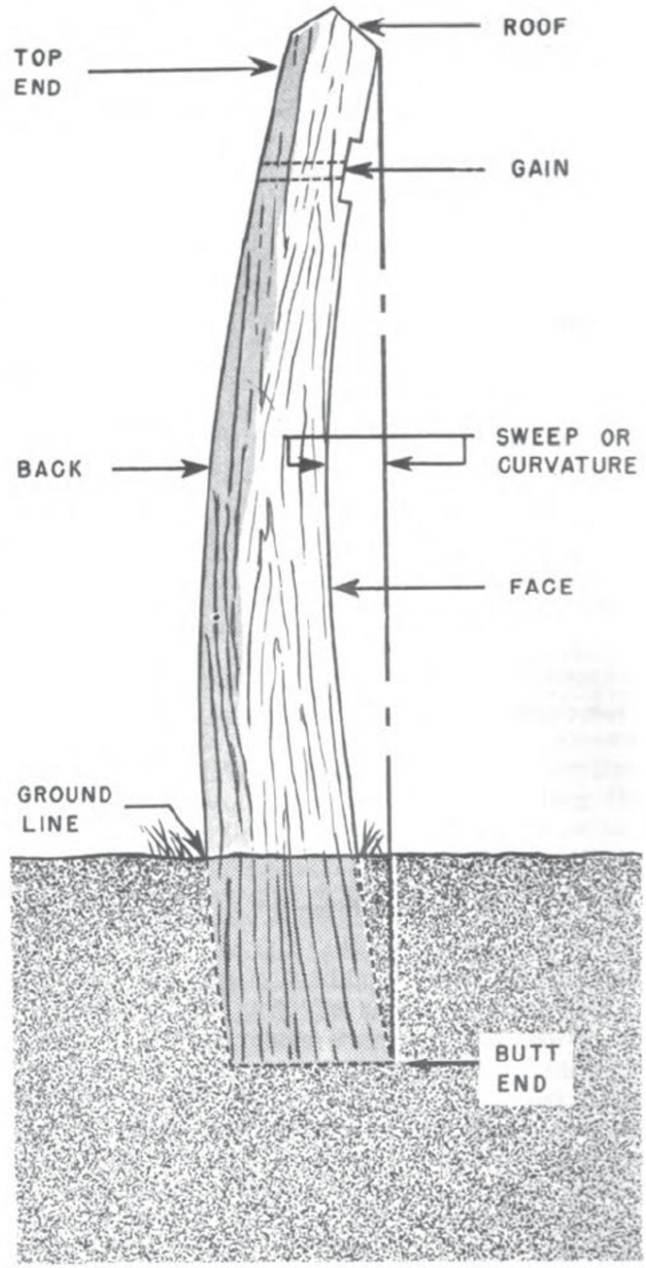
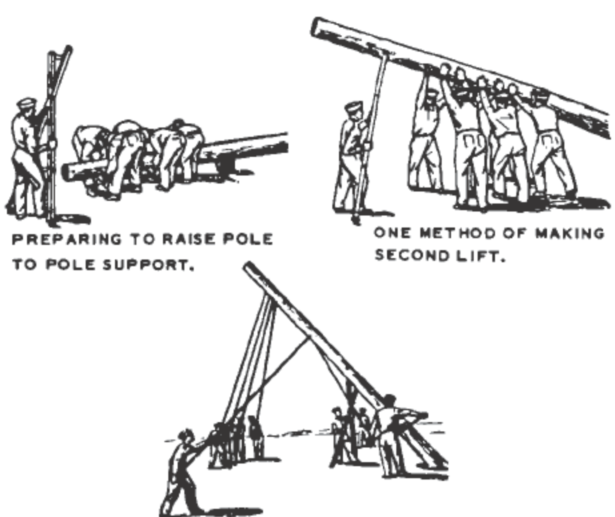


Figure 6-10.-The parts of the pole.

Table 6-1.—Recommended Pole Setting Depths.

Length of pole (ft)	Setting depth (ft)	
	In soil	In rock
20	5.0	3.0
25	5.0	3.5
30	5.5	3.5
35	6.0	4.0
40	6.0	4.0
45	6.5	4.5
50	7.0	4.5
55	7.0	5.0
60	7.5	5.0
65	8.0	6.0
70	8.0	6.0
75	8.5	6.0
80	9.0	6.5



Figures 6-11.—Raising the pole.

forward, and the jennyman moves the pole support forward. Piking continues until the pole is eased into the hole.

A tong-shaped carrying hook is used for moving poles, and a cant hook for turning or rolling them. These hooks will be used in placing the pole so that it will be ready to slide into the hole.

A sloping trench will be an aid in putting the pole into the desired position with relation to the hole. A butt board should be placed vertically in the hole, on the side opposite to the one from which the pole is being eased in. This board prevents the bottom end of the pole from cutting the earth and sending it into the bottom of the hole.

FACING THE POLE means turning it so that the gains face in the proper direction. In straight sections of line, placing alternate poles so that the gains face in opposite directions gives added strength to the line. A dead end pole, however, must always face away from the line. Four pike poles, equally spaced around a light pole, hold it upright while it is being faced; cant hooks supply the leverage to turn it.

When facing is completed, the earth at the base of the pole is replaced and tamped down. Some earth is then rounded about the base of the pole. Back guys and anchors are added if additional support is necessary.

GUYING is done with stranded steel wire; one end attached to the pole, the other to an anchor in the ground. Most guys are for poles, although they should also be used on crossarms that are subjected to unequal pulls on the wires.

The last pole in a line must always be guyed. For a pole other than an end pole, with a small angle (10 to 15 degrees), no guy is required; you can rake (lean) the pole in the opposite direction.

Not all lines are built in a straight line on level ground. Where guys cannot be used because of terrain, key the pole by providing extra supports (racks and so on) on opposite sides of the pole, at butt and at ground surface.

The first step in guying is to provide an anchor, which can be made up of logs and planks. Then cut the guys into the required lengths, and insert the strain insulators. Where only one strain insulator is used, place it mid-way of the guy wire, about 6 to 8 feet from the pole, and a safe distance (at least 8 feet) above the ground. The purpose of the strain insulator is to ensure protection to personnel. If a live wire were to fall on the guy wire, only that part above the insulator would become charged; the part between insulator and ground would be safe to touch.

Attach one end of the guy wire to the pole, either wrapped around the pole or threaded through an eyebolt. Attach the other end to the anchoring rod, and pull the wire taut. Make sure that the guy wire clears other wires attached to the pole by at least 6 inches.

For marshy land, it is better to use push braces in place of guy wires.

MOUNTING THE CROSSARMS is usually done before the pole is raised. However, there may be times when it is necessary to install a crossarm in an existing system. In such a case, a gain must be cut in the pole, and the crossarm should be hoisted up by a type of block and tackle arrangement known as a hand line.

The crossarm assembly (pins, pin insulators, and braces) is always prepared on the ground. Space the two pins that are next to the pole about 14 1/2 inches apart for 2300/4160 voltage; for 7200 volts, place them 29 inches apart; space the end pins about 4 inches in from the ends of the arms. Drive the pins into their holes; secure wooden pins by driving in a nail from the side of the crossarm, and secure steel pins with washers and nuts. Do not drive the nail flush, but leave a space where the pliers can take hold, if the nail must later be removed.

Small insulators can be placed on the pins while the crossarm is on the ground. Larger ones are usually screwed to the crossarm after the latter has been mounted on the pole.

Single crossarms can be used on lines where there will be no great amount of strain; double crossarms should be used at terminals, angles, corners, and other points of added strain.

It may sometimes be necessary to have one pole carry several crossarms, each carrying a different circuit. Clearance between these crossarms depends upon the voltages. The best arrangement is to have the high voltage circuits at the top of the pole, and the lowest voltage on the bottom crossarm.

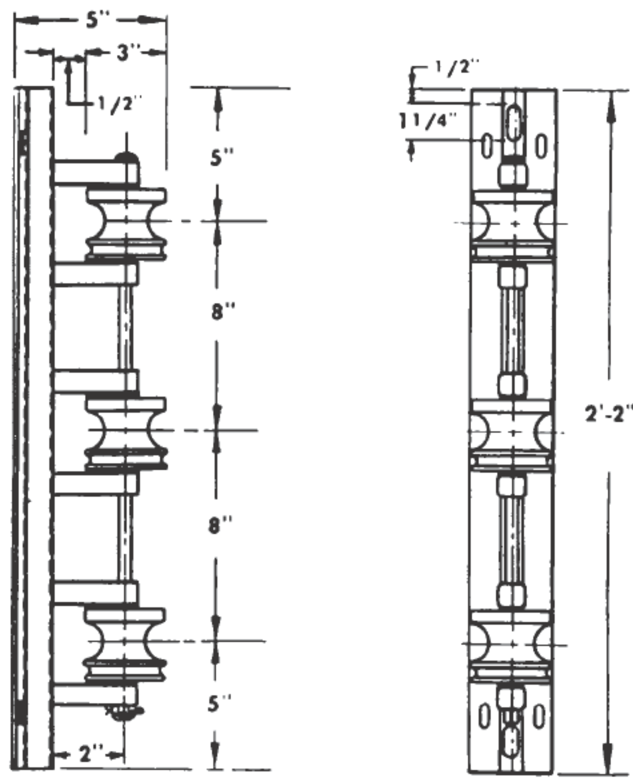
When a crossarm has to be installed after the pole has been erected, there should be one man on the pole, and one on the ground. The block of the lifting device must be attached to the pole at a point above and to one side of the gain in which the crossarm will be placed. The man on the pole bores a hole (slightly larger than the bolt) in the gain, and pushes in a bolt. He then signals to the man on the ground, who begins to hoist the crossarm. The pole man guides the crossarm onto the end of the bolt, and secures it.

STRINGING THE CONDUCTORS is done by paying out the wire from a reel. If the ground is rough or rocky, use a portable reel; if the ground is fairly smooth, mount the reel on a truck.

When one reel has been emptied, and a full one brought up, splice the wires together, with a Western Union splice, or with a sleeve. There are several kinds of sleeves: press on, automatic, twisted, and so on. If the wire is larger than No. 8 solid, never twist it.

If in paying out the conductor you halted at each pole, you would take too long to accomplish a big job. The best method of paying out the conductor is to reel off all, or any necessary length, of the line. Lay the wire on the crossarm, not at every pole but only at road crossings, or at other places where personnel safety, or the condition of the wire, may be endangered. If you can have two crews, one can reel off the wire, and the other lay it up.

Sometimes the wires that are to carry secondary voltages are strung on vertical racks, like that shown in figure 6-12. These racks are formed by spool insulators held in place by a rod. The clevises that hold the spools are secured in the rack, and the rack is bolted to the light pole. A cotter key secures the end of the rod. The insulators are removed from the rod, and the conductors threaded through the rack; then the insulators are replaced on the rod, and the cotter key is put back.



Figures 6-12.—Secondary rack.

These secondary racks are good in some places, but in general, the clevis is better. If the insulation wears from the wires, and the wires touch the clevis, the circuit will not short out; however, touching the clevis will result in electric shock.

In stringing the conductors, first reel the wire out along the ground, keeping it straight. Then climb the pole, bore the holes, pull the wire up with a hand line, and lay the wire in the clevis. Using this method, you have to climb each pole only once.

ADJUSTING FOR TENSION is an important factor in the installing of an overhead system. Wires that are pulled too tight will break under the strain of high winds, a coating of ice, or a contraction of the metal in the conductor. Wires that are too loose may expand under high temperatures, and dip so low as to endanger personnel.

The amount of sag depends upon three factors: length of span, temperature at the time the wires are strung, and expected weather conditions. Charts are available, giving the allowable amount of sag in relation to these factors.

The following table of sags for different wire sizes, at specified temperatures and for specified lengths of span, should provide you with helpful information.

Your responsibility, as far as sag is concerned, will be pulling the wire until you have obtained the specified dip. The simplest method is by sighting, using two men for this purpose. The other methods commonly used are the use of a dynamometer, or the counting of the oscillations of a vibrating wire.

In the sighting method, nail a marker to each of two consecutive poles, at the height which corresponds to the specified sag. Climb the pole and sight from the marker to that on the next pole, to determine if the lowest dip of the wire is in line with these markers. Signal to the man (or men) on the ground, to tighten or slacken the wire until its dip is in line with the markers.

Table 6-2.—Sags for Hard and Medium-Drawn Bare Copper Wire, for Different Span Lengths.

AWG Number	Temperature (degrees F)	Sag (in inches) for span lengths of					
		100 ft	125 ft	150 ft	175 ft	200 ft	250 ft
6	30	5.5	8.5	13	18.5		
	60	8	12	18	24		
	90	12	17	23.5	30		
4	30	5.5	8.5	13	18.5	25	35
	60	8	12	18	24	32	42
	90	12	17	23.5	30	39	50
2	30	5.5	8.5	13	16.5	20	29
	60	8	12	18	22	26	36
	90	12	17	23.5	28	33	44
1	30	5.5	8.5	13	15.5	18.5	24.5
	60	8	12	18	21	24	31
	90	12	17	23.5	28	31	39
0	30	5.5	8.5	13	15.5	18	23.5
	60	8	12	18	20.5	23	29
	90	12	17	23.5	27.5	29.5	36
00	30	5.5	8.5	13	15	17	21
	60	8	12	18	20	22	27
	90	12	17	23.5	26	28	34
0000	30	5.5	8.5	13	14.5	16	19
	60	8	12	18	19	21	24
	90	12	17	23.5	25	27	30

A block and tackle is used for pulling the wire. On a short line, the block and tackle can be attached to the pole; on a long line, it is better to have it on the ground. As soon as the wire has been drawn to the desired tension, the block and tackle should be secured by snubbing, to keep the wire from slackening off.

If you use a dynamometer to tension the wire, insert it between the wire and the pulling source. The tension on the wire is read directly from the dial of the dynamometer.

To use the oscillation method, set the span to vibrating by striking it from the top of the pole, or by pulling down and releasing a piece of rope attached to the middle of the span. The number of vibrations can be conveniently measured near a pole. Be sure to allow time for wire creep before counting the vibrations.

When the wire is vibrating, count the number of vibrations that it makes in a 15-second period. You will have to have access to a chart that converts these readings to equivalent sag. If the number of oscillations does not indicate the required sag, increase or decrease the tension in the wire, as necessary, and set it vibrating again.

TYING IN THE WIRES after they have been tensioned and dead-ended can be done in several different ways, and it would be advisable to ask some more experienced man to show you how it is done.

Small conductors may be dead-ended on steel pin insulators mounted in double crossarms. The end of each wire is brought around the side grooves of the pin insulator in a figure-eight design. After the wire has been brought around the insulator (or through the clevis), serve four or five long wraps around the wire, tighten with your pliers, wrap two or three buttons, and bend back about two inches over the serve. Never serve wire larger than No. 6 weatherproof, or No. 10 bare hand-drawn.

When larger conductors are to be dead-ended, stronger insulators are used. There are several types of dead-end insulators; a type often used is the suspension insulator, sometimes referred to as the disk or bell type, illustrated in figure 6-13.

The conductors are fastened to the insulators with tie wires, usually about 3 feet in length. The metal of the tie wire should be soft enough so that it can be snugly wrapped around the conductor and the insulator. In tying these wires, remember that someday you, or another Construction Electrician, may have to untie them. Do not cut the end of the wrap too close, or it will be difficult to get hold of later.

Underground Systems

Lead-sheathed cable, usually the multiconductor type, is used for most underground circuits. Under the lead sheathing, each conductor is insulated with layers of oil-soaked paper, or with varnished cambric tape, spirally wrapped.

Any moisture working its way underneath the sheath can cause a voltage breakdown between conductors. Exclude all possible sources of moisture while you are working on the cable. Wear sweat bands on your wrists, and wipe your hands frequently on dry rags. Keep materials and tools dry. Place a temporary awning over the working space, to minimize water seepage into the manhole or splicing chamber.

REMOVE THE SHEATH from cable by making a ring cut at the points between which the

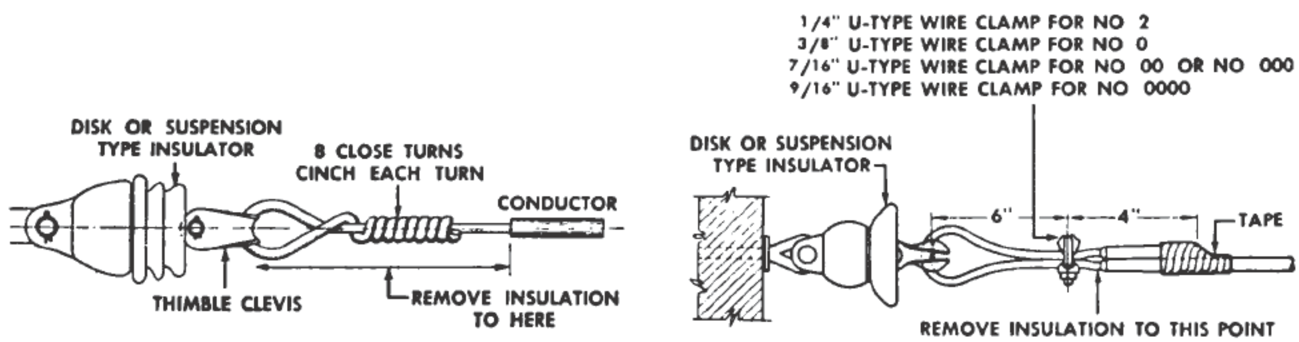


Figure 6-13.—Insulator dead end.

sheath is to be cut away. Do not cut completely through the sheath in making the ring cuts; the best method is to tap the sheathing knife lightly with the hammer.

After the sheath is ringed, make a lengthwise cut between the ring and the end of the cable, and peel the sheath away from the cable. When within about one inch of the end, begin working the sheath back and forth. This is the best way to make sure that you will not injure the insulation in removing the sheath.

Remove belt insulation by unwrapping and tearing it off. Do not cut it with a knife. At the point on the cable where the sheath still remains, wrap several layers of varnished cloth tape. You can then tear off the belt insulation against this tape, and know that the belt insulation has been removed for the same surface extent as that from which the sheath was removed.

To remove insulation from individual conductors, tie a clove hitch around the insulation to prevent unraveling, and then make a cut around the insulation. Trim the insulation as you would sharpen a pencil. Single-conductor high-voltage cables should be cut in two with a hacksaw. You can then make a lengthwise cut, as you did on the sheath; or you can slide the insulation off the end of the conductor.

TESTS FOR MOISTURE should be made on the oil-soaked paper or varnished cambric used for insulation. Immerse the samples in oil heated to a temperature of 125 C (about 255 F). Bubbling or cracking indicates that there was moisture on the sample. Suspend work until the officer supervising the work decides what procedure to follow. Be very sure that you do not introduce moisture from your hands or your tools.

Before INSTALLING CONNECTORS, wipe off all dirt and excess compound from the ends of the copper conductors. If the strands of the conductor tend to spread, bind them with wire; this will make it easier to slip the connector over the end of the conductor. The conductor must be shaped to receive the connector; never spread the connector to fit the conductor.

Make sure that the inside of the connector is well tinned, and free of excess solder. Then slip it over one strand of the conductor, and work it well past the center. Insert the end of the other conductor until it joins the first, and then center the connector over the joint.

Never use an oversize connector by building up the conductor with solder. The conductivity of solder is less than that of copper. However, if you must use an oversize connector, build the conductor up with copper wire or copper inserts.

Wrap cheesecloth, rolled into rope form, around the ends of the insulation on the conductors, to protect the insulation from hot solder. Pour the solder over the end of the connector and into the slot; when the strand and connector have become hot enough, the solder will flow through the cable strands and out at the ends of the connector. Have a second ladle ready, for catching the excess solder.

Taping oil heated to about 230 F is used to flush the joint, so as to remove dirt, copper filings, or moisture left on the insulation after soldering. After the joint is flushed, cover the surface of the cable insulation with taping oil, and apply one-half inch half-lapped tape over the exposed strands.

On large conductors, where you want a tapering effect at the outer edges of the taping area, make the slope by applying each layer slightly shorter than the preceding one. On small conductor cables, it may be preferable to use 1-inch tape throughout, rather than 1/2-inch tape.

As you reach the end of a roll of tape, lap off three inches of the next roll under the trailing edge of the roll you are finishing. As you finish taping each conductor, bind the final turn in place by passing the end of the tape under the preceding turn. Pull the end tight, and cut off any excess.

Wiping the Joints

After you have completed the taping of the conductors, you are ready to solder the joint and fill it with compound. Center the sleeve, and mark the cable at each end of the sleeve; then move the sleeve aside, so that you can scrape the cable sheath and coat with stearine.

Cut off the neutral conductor (if included in the wipe to proper length), and fan out the strands to lay on the cable sheath. Tin the strands and bind them to the cable sheath with six turns of No. 6 copper wire.

Then center the sleeve again over the splice area, and dress in the ends to form a tight fit around the cable. Figure 6-14 indicates the process of dressing the sleeve. Rotate the sleeve around the cable, meanwhile tapping the ends lightly with a hammer. The angle of taper depends upon the size of the sleeve.

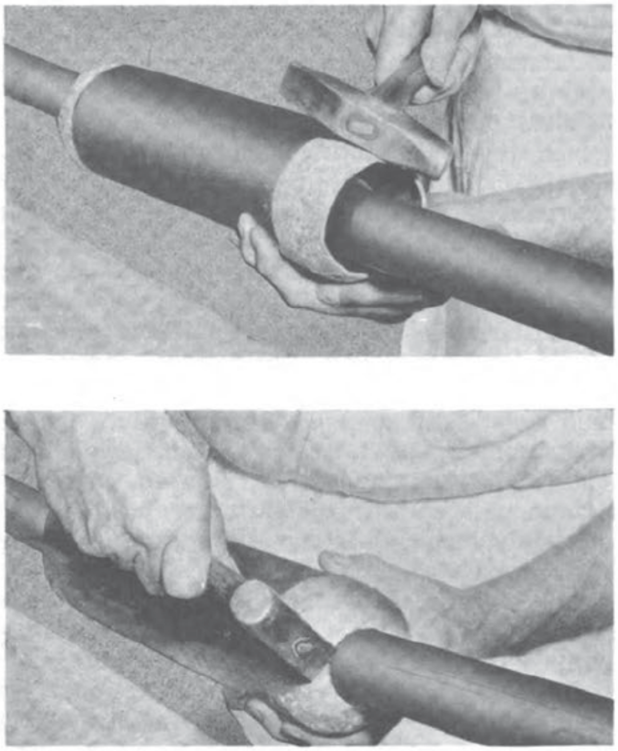


Figure 6-14.—Dressing the sleeve: A, beginning the dressing process; B, sleeve dressed to final size.

When the sleeve is shaped to the cable, the joints must be given a tight seal. Apply pasters at the ends of the sleeve, and also to the cable, about two inches beyond the joint (one inch is sufficient on small cables).

These pasters are strips of gummed tape, applied to protect the cable from solder. (After the joint has been completed, the pasters are removed.)

You are now ready to solder the joint between sleeve and cable. Using an asbestos glove, wipe the hot solder around the joint with one hand, as you pour the solder with the other.

To fill the spliced area beneath the sleeve with compound, make an opening on the upper side of the sleeve, one near each end, as indicated in figure 6-15. One opening should be a small slit, the other should be a circle about 3/4 inch in diameter, and tapered at a 45-degree angle.

Do not heat the compound in the container in which it comes, but use a teakettle or other convenient container. Do not place the kettle directly on the lighted furnace or torch; use a metal baffle. Stir the compound, to make sure that it heats uniformly. Maximum temperature should be about 300 F.

If the compound shows evidences of dirt, or if it bubbles or crackles when heated above 212 F for 15 minutes, do not use it.

Pour from the spout of the kettle, or through a funnel, into the larger opening in the sleeve, until the compound overflows at the lower end. All entrapped air must be removed from the splice. Then let the joint cool for an hour, and add more compound, if necessary, to compensate for contraction.

When the joint has cooled, seal the opening by bending the lips of the opening back into position, and peening the edges to make a tight seal. Scrape the seal area, coat it with flux, and apply pasters. Then solder the area, with soldering iron or wiping solder, to complete the seal.

JUNCTION AND SWITCH BOXES provide a convenient means of connecting branch circuits without any interference with the mains. A junction box should be so located that the minimum bending radius, in training the cable, is not less than eight times the overall diameter of the cable. Switch boxes are available for use with high or low voltage circuits, and the interconnection of circuits can be changed without removing the cover from the box. A typical switch box is illustrated in figure 6-16.

POTHEADS are used for sealing the cable sheath, and they also provide a terminal where attachments can be made to overhead lines and to equipment. The inside of the pothead should be inspected for burrs. The pothead body is mounted on a pole, and enough cable must be available for proper installation. Three inches of cable should extend above the porcelain tube after the pothead has been mounted and the cable trained into final position. Figure 6-17 shows a disassembled pothead, and figure 6-18 is a diagram of a single-conductor disconnecting pothead.

Potheads, as well as junction and switch boxes, must be inspected at least yearly. Grounding should be checked, and a temperature check should be made with the bare hands, since this equipment should not run warm. If undue heat is present, look for loose or corroded contacts, or for moisture causing current leakage.

Cable sheath on that portion of the cable from riser pipe or duct entrance to the junction box, switch box, or pothead, should be checked periodically, for cracks, corrosion, or pitting.

Some type of GROUNDING must be provided for underground cable, to prevent current leakage

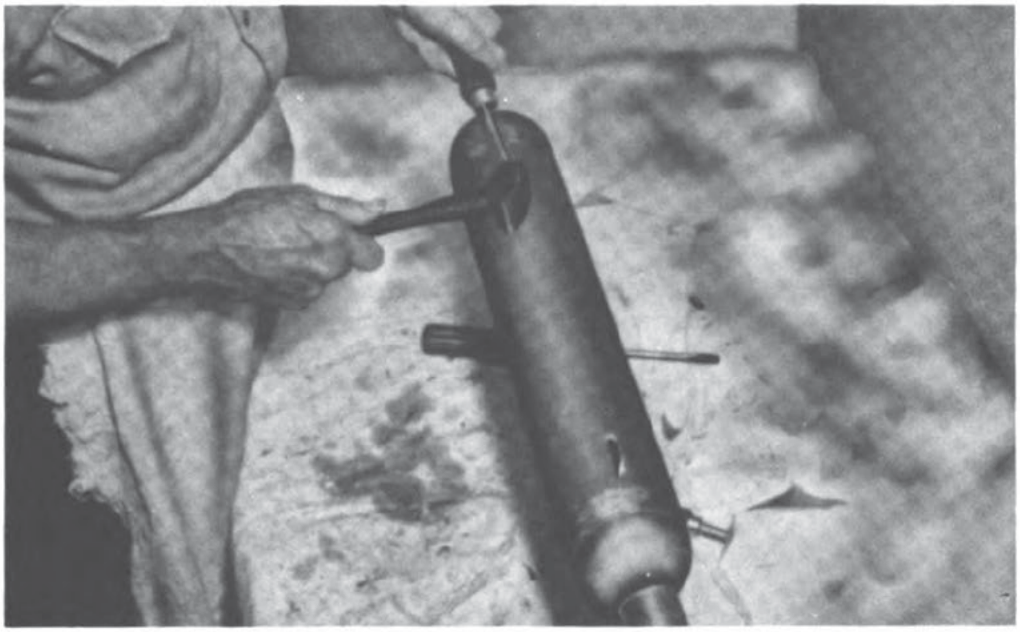


Figure 6-15.—Making openings for compound.

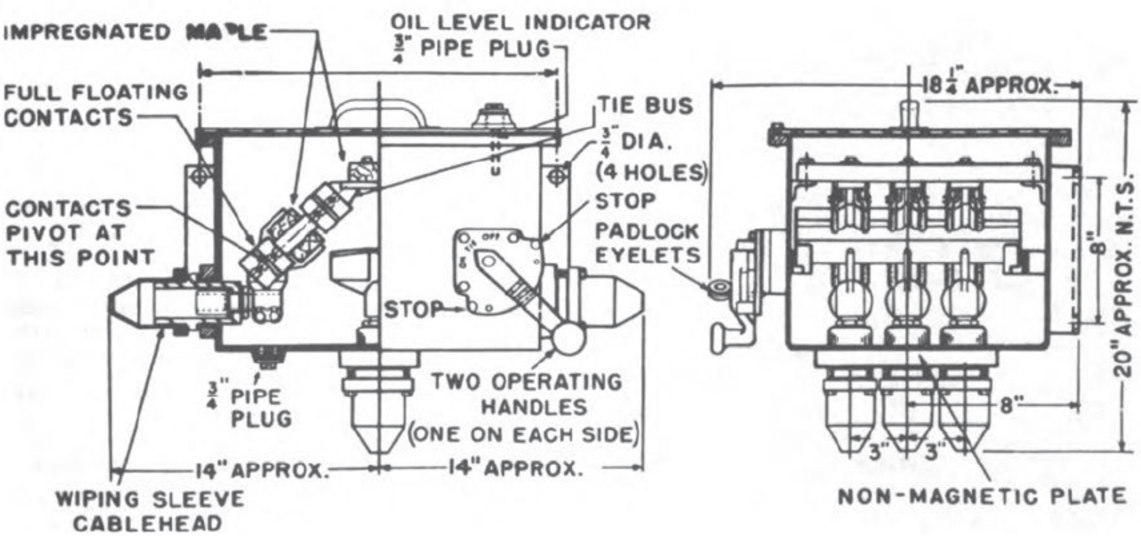


Figure 6-16.—A 600-volt 3-way switch box.

from the cable damaging the sheath. Ground rods provide an established path to earth for any such leakage. The resistance of these ground connections must be kept as low as practicable; in no case should resistance exceed 25 ohms.

For buried cable, the ground rods are driven about 18 inches from the cable. The top of the rod should be 6 inches below ground level, and the bottom should extend below the permanent moisture line. When the cable is installed in a conduit, the ground rods are driven through the bottoms or side walls of the manholes.

No. 6 stranded copper wire is used for the connections between cables and ground rods. The strands of the ground wire should be untwisted, and trained to parallel positions. This increases the area in contact with the sheath.

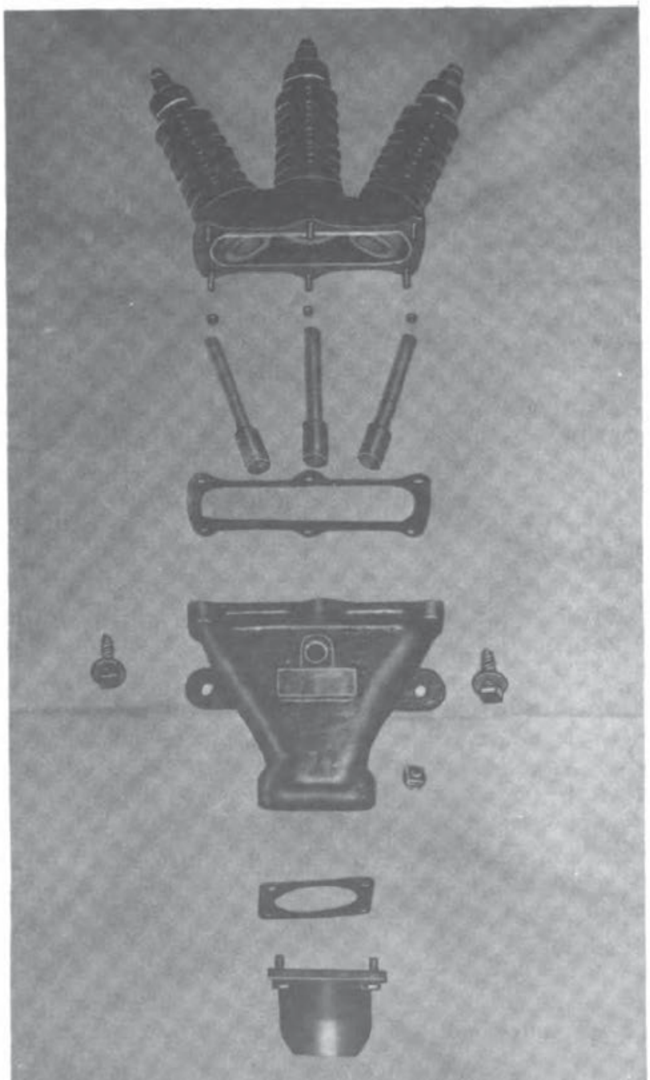


Figure 6-17.—Disassembled pothead.

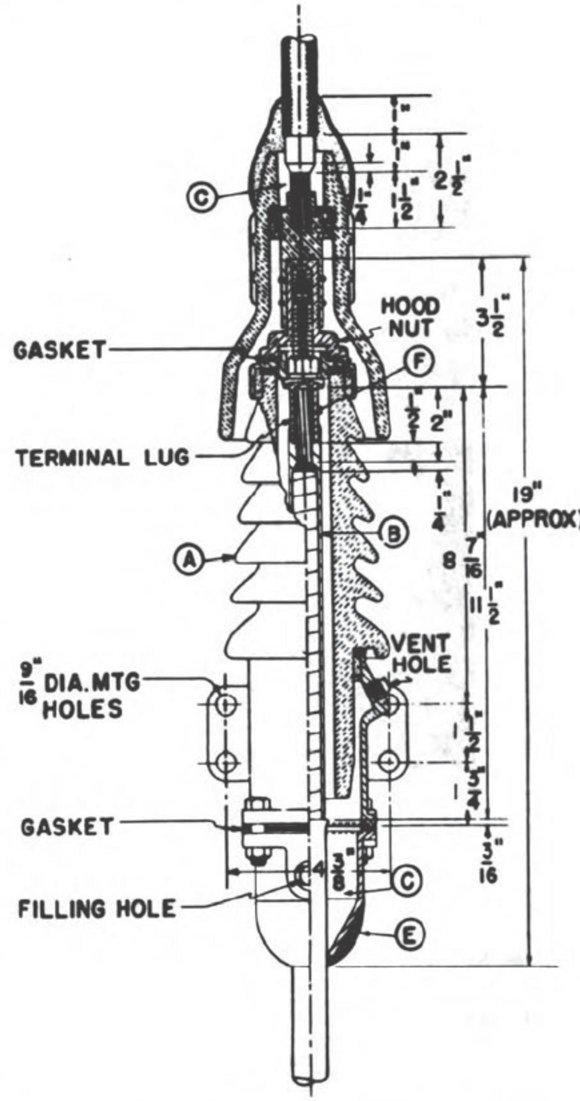


TABLE OF MATERIALS		
ITEM	REQUIRED	DESCRIPTION
A	1	DISCONNECTING POTHEAD (SINGLE-CONDUCTOR, 7 1/2 KV)
B	2 ROLLS	VARNISHED-CLOTH TAPE (1 IN X 18 YD)
C	1 GAL	INSULATING COMPOUND
D	1 PT	TAPING COMPOUND
E	4 LB	WIPING SOLDER
F	1 LB	SWEATING SOLDER

Figure 6-18.—Single-conductor 7.5-kv disconnecting pothead.

Where cables are connected to junction or switch boxes equipped with wiring caps, never ground the cables at the boxes. Where boxes are equipped with stuffing cap entrances, install a jumper wire from the sheath of each cable to its stuffing cap, If the electrical connection between cable sheath and pothead body is poor, install a jumper between them.

DISTRIBUTION TRANSFORMERS

A-c generators are usually wound for a relatively high voltage. If 220 volts, or even 110 volts, were to be transmitted directly from generator to equipment, an extremely large wire would be needed; a combination of small wire and high voltage, on the other hand, would produce dangerous conditions at the point of consumption. Since the wire capable of transmitting the high voltage is not practical, and the small wire is not safe, an electrical device called a distribution transformer is used, to LOWER VOLTAGE between distribution and consumption points.

In cases where generator voltage is lower than that required for the operation of some piece of equipment, it is necessary to RAISE VOLTAGE between distribution and consumption points. Here again the distribution transformer is used. Why it is possible to use the same device to accomplish two opposite effects will become clear as you study the principle and design of this transformer.

Principle of the Transformer

In its elementary form the transformer is an iron core carrying two coils of wire. The core forms a closed magnetic circuit; the coil on one leg of the core is formed of many turns of fine wire, whereas that on the other leg is of a few turns of heavy wire. Figure 6-19 shows these essential parts.

The coil to which the power is applied is always called the primary coil, and the other is the secondary coil. The amount of step-down (or step-up) in voltage depends upon the relative number of turns in the primary and secondary coils.

Suppose that the generator voltage is 220 volts, and that you want a secondary voltage of 110 volts. You would use a transformer with a

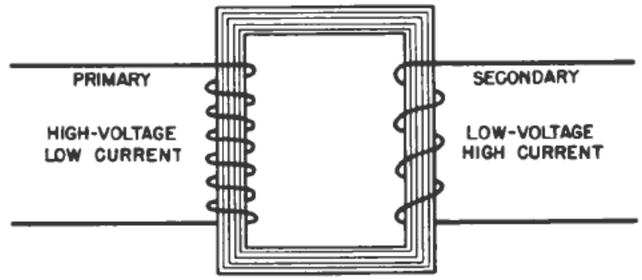


Figure 6-19.—Elementary distribution transformer.

primary coil of twice as many turns as the secondary coil. This gives what is known as a step-down ratio of 2 to 1; the voltage in the secondary coil is only one-half that of the primary coil. However, the current in the secondary coil is twice that in the primary coil.

Where the primary voltage is lower than the secondary voltage, the secondary coil of the transformer will have more turns than the primary coil. If the secondary has twice as many turns as the primary, voltage will be twice that of the primary, and current one-half that of the primary. If the secondary has 10 times as many turns as the primary, voltage will be 10 times that of the primary, and current 1/10 that of the primary.

When the number of turns is the same in both coils, voltage and amperage in the secondary coil will be practically the same as in the primary, except for a very small percentage loss.

If the primary coil of a transformer is connected to the power source, but the secondary coil is unconnected, only a very small current (a fraction of an ampere) will flow. If you were to put an appliance between the two ends of the secondary coil, just enough current would flow in the primary to deliver the required wattage to the appliance.

The step-down ratio of 2 to 1, mentioned earlier, represents a simple case in reduction of voltage. There will be times when your distribution voltage will be much higher than 220 volts, and it will be necessary to use a transformer with a much greater step-down ratio.

For example, a 2300/4160-volt 4-wire primary main serving the area of an advanced base may require a step-down ratio of about 20 to 1, in order to reduce the voltage transmitted by a single secondary to a safe 115 volts. Tying the primary between neutral and line ensures that the primary coil will be energized by only 2300

volts. Winding the primary with 800 turns, and the secondary with only 40 turns, ensures that the voltage in the secondary will be 1/20 that of the primary.

Single-phase distribution transformers used on 2300-volt mains are usually constructed with two secondary windings. This gives the same result as two separate transformers connected to the same primary winding. The secondary windings may be connected in series or in parallel, depending upon the desired voltage and current output. These two methods of connecting the secondary mains are illustrated in figure 6-20.

In view A of this figure, the secondary windings are connected in series, and you have a setup known as a 3-wire single-phase secondary main. The three leads tapped from the secondary winding and connected to the secondary mains makes it possible for you to obtain 230 volts and 115 volts from the secondary main.

In view B, the secondary windings are connected in parallel, and you have the setup known as 2-wire single-phase secondary main. The advantage of this arrangement is that, although the output is only 115 volts, you can obtain twice the current drain.

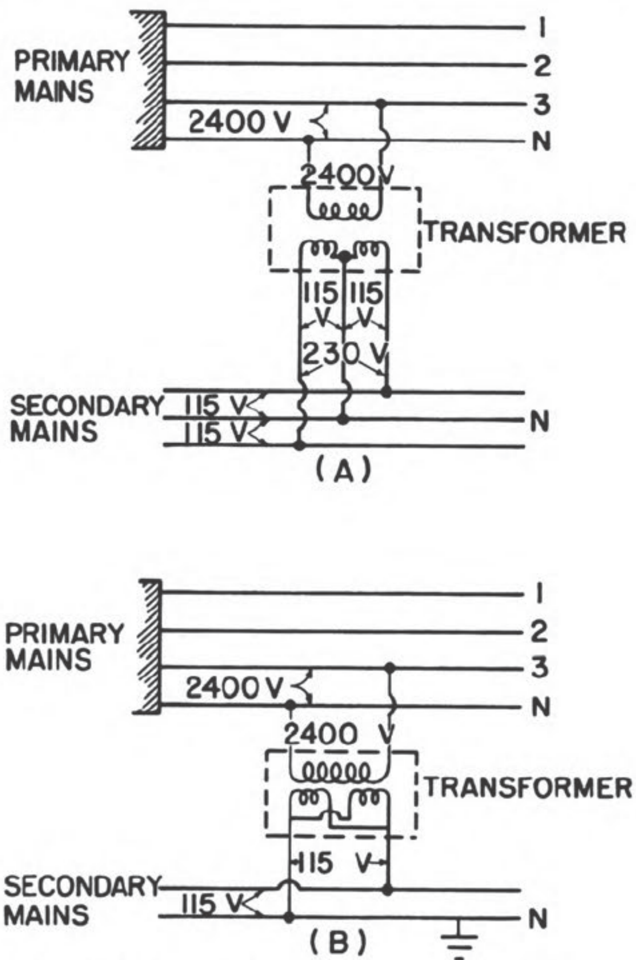


Figure 6-20.—Single phase transformer, with secondary windings connected in series, and in parallel.

Types

The manner in which primary and secondary coils are arranged on the core of a transformer differs, as indicated in figure 6-21. The type shown in view A is known as the CORE type. Each leg of the core carries both a primary and a secondary winding. This is the type used in most high voltage transformers.

At view B, you see the SHELL type. A middle leg is added to the core type, and the primary and secondary coils both are wound around this added leg. This is the type of transformer used for heavy current loads.

The core shown at view C is formed like a cross; it is a combination of core and shell types, and has some of the advantages of each. You will hear this referred to as the DISTRIBUTED type of transformer.

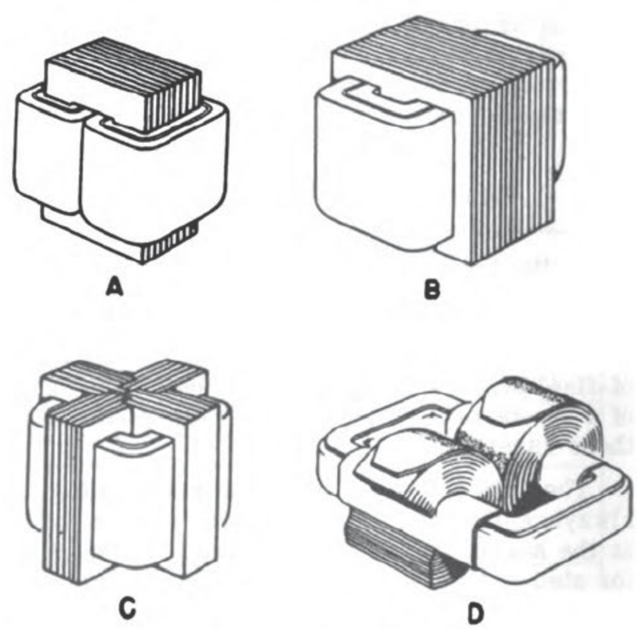


Figure 6-21.—Transformer cores: A, core type; B, shell type; C, distribution or crucifer type; D, wound core type.

View D shows the WOUND-CORE type. A ribbon of sheet steel is wound in a spiral on each leg of the transformer. This is the type of core generally used in low-voltage distribution transformers.

Cooling Method

All distribution transformers are placed inside a metal case. This protects them against dirt, moisture, and mechanical damage. When the transformers are in use, heat develops within these cases, and must be removed as quickly as it develops. Small transformers may be air-cooled, but the larger ones are likely to be the oil-cooled or the askarel-immersed types. (Askarel is a synthetic nonflammable insulating liquid.)

In low voltage transformers, the air inside the case conducts the heat to the metal container, and the air outside conducts the heat to the surrounding atmosphere.

For primary and secondary voltages of 600 volts and less, natural circulation of air around the core and case, and through the windings, is an adequate method of cooling. The transformer may also be provided with ventilating enclosures. Air-cooled transformers with a voltage rating above 600 volts, and a capacity of 100 kilovolt-amperes (kva) and above, must be equipped with lightning arresters or with protective gaps.

In the larger distribution transformers, heat develops faster than the inside air can conduct it to the metal case. These transformers are often filled with oil, which transfers the heat more rapidly than the air can do. If the container surface is corrugated, it offers a greater area from which the heat can be removed by radiation. Figure 6-22 shows a 7200-volt transformer that in operation is filled with oil. When the transformer must be emptied, the oil can be drained through a valve at the bottom of the container.

Askarel-immersed transformers are filled with a nonflammable, noncorrosive, insulating liquid. A nonflammable askarel-immersed type must be used for power or lighting transformers installed indoors.

Connections

You have learned that a transformer has two coils; the one that is connected to the power source is always known as the primary coil, and the one connected to the equipment to be operated is always the secondary coil. Secondary windings, as we have seen, may be connected in series or in parallel.

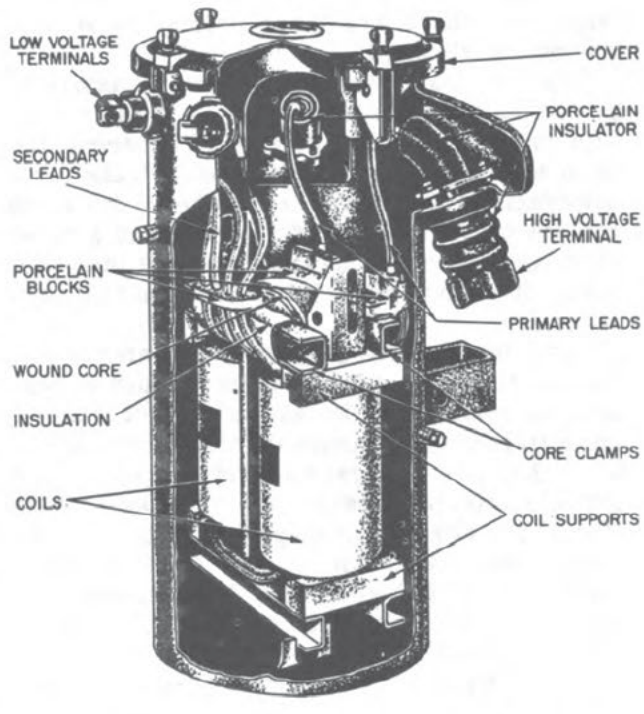


Figure 6-22.—Cutaway view of a 7200-volt distribution transformer.

The transformer with only one primary winding is a single phase transformer, and its output can be used only to operate single phase equipment. However, you will at times be working with 3-phase transformers, and you must understand the various ways in which primary and secondary connections can be made.

If your generating station is producing the same 3-phase voltage that is required to operate the motors and other equipment, there is no more of a problem than with the single-phase equipment. All you need to do is to tie your 3-phase equipment directly to the primary mains. But on a large base, where buildings and equipment are at some distance from the generating station, and where there is considerable variation in the voltages required for different equipment, a high voltage generator must be used. With this high voltage generator, you will use a 3-phase transformer makeup.

The 3-phase transformer is available as a single unit, enclosed in a metal case. One iron core serves as a common path for the magnetic

lines; but there are three primary and three secondary windings.

You can make your own 3-phase transformer, if you have three single-phase transformers with the same rating. Properly connected, they form a 3-phase transformer bank. This has an advantage in that if one transformer burns out, you can wire for an open delta instead of a closed delta. In this way, you can use the 2-transformer bank, although it has a lower efficiency (about 60 percent).

You learned in chapter 2 of this training course that the difference in timing between induced voltages is known as phasing, and that this difference is measured in electrical degrees. In a 3-phase voltage, each of the voltages is 120 electrical degrees out of phase with the other, or 120 degrees apart. In the 3-phase transformer, therefore, each of the primary coils will be 120 electrical degrees apart, and each of the secondary coils will be 120 electrical degrees apart.

If a 3-wire delta distribution system is employed, the voltage between lines will probably be 2300 volts. If a 4-wire Y system is used, it will probably have 2300 volts from neutral to line, and 4160 volts (that is, 2300 times the square root of 3) from line to line. These two systems are illustrated in figure 6-23.

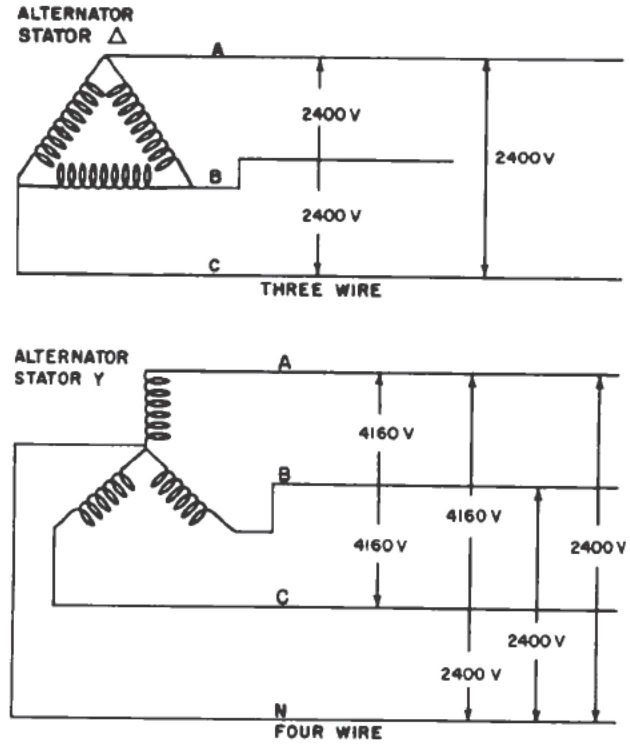


Figure 6-23.—High voltage 3-wire and 4-wire distribution systems.

The primary and the secondary windings of the 3-phase transformer may be either delta or Y-connected. A delta-delta connection means that the primary windings and the secondary windings are both connected in delta; a Y-Y connection indicates a 4-wire primary main, and a 4-wire secondary main; a delta-Y connection indicates a primary connected in delta, and a secondary connected in Y. Diagrams of these three types of connections, and also of a V-connection, are shown in figure 6-24.

Each type of connection has its specific advantages. In general, a Y-connected transformer has the advantage of producing secondary voltages for light and power. When used as a stepup transformer, it requires fewer turns in the secondary windings (since line voltage is 1.73 times phase voltage). Its grounded neutral wire maintains a balanced load. On the other hand, a delta-connected transformer can be operated, if load is reduced about 40 percent, after one phase has burned out.

In a setup such as that shown at view A of figure 6-24, there are 2300 volts across each coil of the delta primary, since the line to line voltage of the primary main is 2300 volts. Each primary coil has 800 turns, and each corresponding secondary coil has 80 turns. Reduction ratio is 10 to 1; there would be no difficulty, therefore, in operating any 230-volt 3-phase equipment. No additional transformer will be needed for 115-volt equipment, since the center-tapped winding makes this a 3-phase 4-wire 115/230-volt secondary main (or 110/220 volts).

The secondary main represented by the top line, however, carries a voltage of about 190 volts; never use it for 110-volt equipment. However, if this main is tied in with the one below it, and with the bottom line (that is, with the two hot lines), the voltage will be neutralized to 230 volts.

If you are curious as to why the line carries 190 volts, you may be interested in the diagram in figure 6-25. Each side of the triangle represents 230 volts. (The triangle is equilateral; that is, equal-sided.) If you run a line from the apex at the left, bisecting the opposite side, you have two right triangles; each has a side equal to 230 volts, and a side equal to 115 volts.

From your basic mathematics, you know that in any right triangle, the square on the hypotenuse

(longest side of the triangle) is equal to the sum of the squares on the sides. When one side is unknown, you can find its square by subtracting the square of the other side from the square of the hypotenuse.

In figure 6-25, the unknown side is the one common to the two triangles. Square the side equal to 115 volts, and the result is 13,225; subtract this from 52,900, which is the square of 230; then take the square root of this difference. Your answer will be about 190 volts, allowing for voltage losses.

Notice that in the Y-connected primary in view B of figure 6-24 there are four wires, whereas there are only three wires for the delta primary at view A. The fourth wire is the neutral, but with a delta connection no neutral is used.

With the Y-Y connections shown, the 2300/4160 primary main is stepped down to 120/208 volts. With this setup, you can serve both single-phase and 3-phase equipment.

View C of figure 6-24 shows the delta-Y transformer. By connecting the secondary in Y, you can take care of 3-phase power and single-phase lighting from the same line. The single-phase load is evenly distributed by using the neutral wire and alternate lines. You could, of course, supply a 115-volt single-phase lighting system from a delta-delta transformer bank (view A), by grounding the mid-tap of one of the transformers. However, this latter arrangement has the disadvantage that it puts the entire 115-volt load on one transformer.

The V-connection shown at view D of figure 6-24 is the type of connection that you would have if a single-phase transformer in a delta-delta transformer bank were to burn out. The

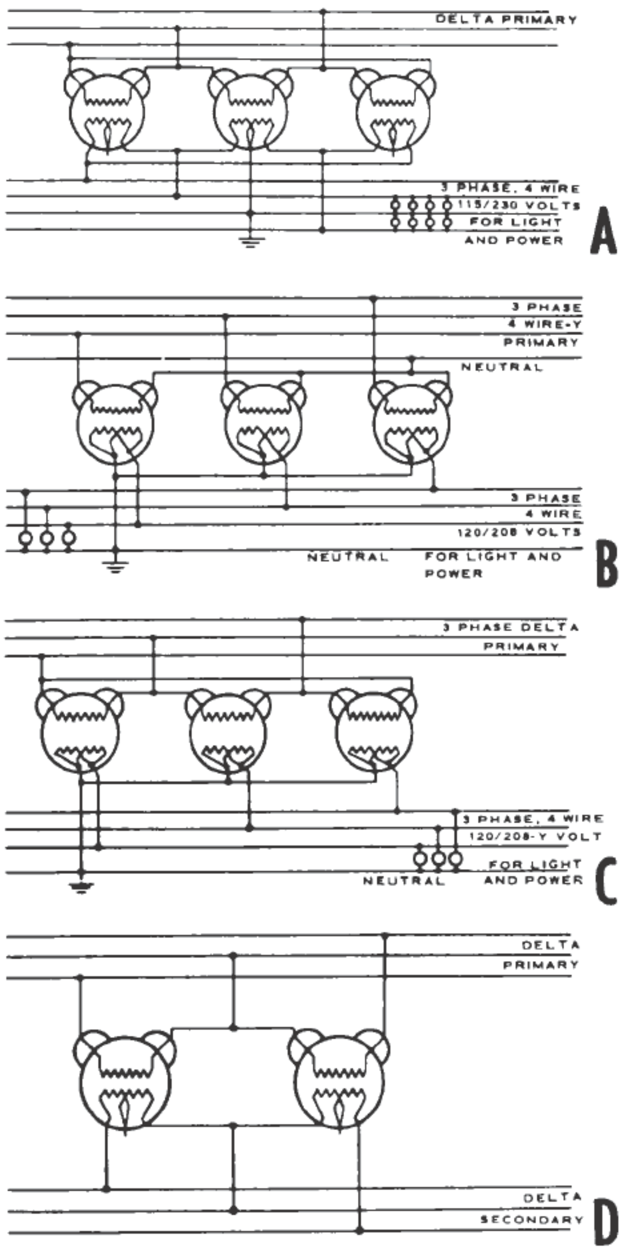


Figure 6-24.—Three-phase transformer connections: A, delta-delta; B, Y-Y; C, delta-Y; D, a V connection.

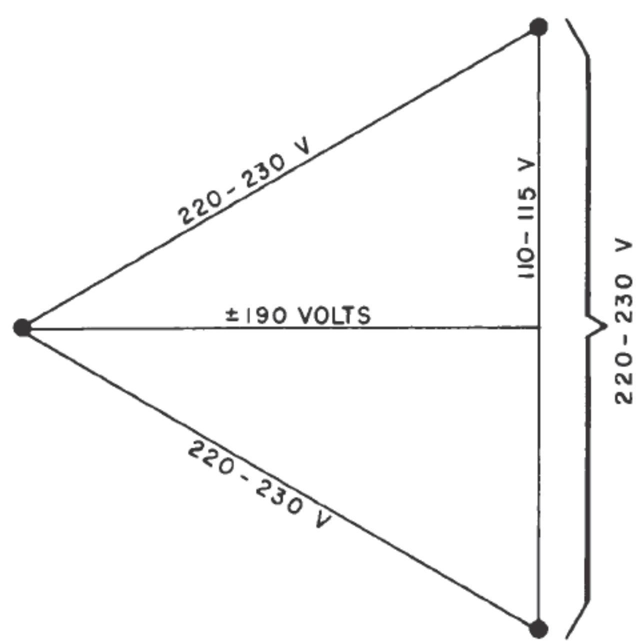


Figure 6-25.—Voltage vector diagram, delta connection.

connection would still produce the rated 3-phase voltage on the secondary; but because you now have only two windings, instead of three, to take care of current, only about 60 percent of the rated transformer load can be handled. (If one phase of a Y-connected transformer burned out, you would have to stop operation entirely until the faulty phase was replaced.) If the power drain of the equipment on the V-connected transformer is more than 60 percent of rated load, you should disconnect the less important equipment.

As you can see from the foregoing paragraphs, the big advantage of the delta-connected transformer bank is that it can be operated under emergency conditions.

Load

Most Navy transformers are rated according to the kv-a load that they can carry safely and continuously, and with a temperature rise not exceeding 80 C (176 F), under the following conditions:

1. The transformer is maintaining rated (or slightly higher than rated) secondary voltage, and rated frequency (cycles).
2. Temperature of the surrounding atmosphere is not above 40 C (104 F).

Actual temperature of any part of the transformer is the sum of the temperature rise of that part, and the temperature of the surrounding air.

When current is being supplied to a motor from a transformer, the kv-a rating of the transformer should be at least as high as the hp rating of the motor; that is, a 75 hp motor would require 75 kv-a in transformer capacity. However, since small motors usually have a relatively lower efficiency than that of transformers, they must be supplied with a larger transformer capacity whenever they are to be run at slight overload, or at nearly full load for most of the time that they will be in operation.

Power Factor

Power input to the primary coil of a transformer is practically equal to power output of the secondary coil. However, there may be small losses; if so, the actual kikowatt output is less than the kv-a output, since the latter is the apparent power output.

The power factor of a transformer is computed in the same way as the power factor of any circuit. It is the ratio between apparent power and true power, and is expressed as a ratio. You will find a discussion of power factor in the following chapter.

In computing the load that a transformer can carry, therefore, it is necessary to know whether the power factor is 100 percent. When it is less than 100 percent, the transformer load must be reduced accordingly.

Grounding

Each transformer tank must be grounded. On these grounding conductors—as on any grounded circuit-be careful NEVER to get into series with the grounded return while the line is hot. The grounded return carries the same amount of current as the primary.

The top of the ground rod must be 6 inches below ground level, and must be located at least 12 inches from the base of the pole upon which the transformer is mounted.

Polarity

All transformers carry standard polarity markings. The letter H is used to indicate the high voltage terminals, and the letter X is used for secondary terminals. The extreme right-hand lead, as you face the high voltage side of the transformer, is marked H_1, the next is H_2, and so on. The secondary terminals, X_1, X_2, and so on, may be in numerical sequence or they may be in reverse order.

These markings are guides to the polarity of the induced voltages, and therefore must be understood if you are to make the correct delta or Y connections on a 3-phase transformer.

If the H_1 and X_1 leads come from the same side of the transformer, the polarity is called SUBTRACTIVE. This is because the voltage of the low-voltage winding opposes that of the high-voltage winding.

If the secondary terminals are marked in the reverse order, the X_1 lead will be brought out on the opposite side of the transformer from the H_1 lead. In this case, the voltage of the low-voltage winding aids the voltage of the

high-voltage winding, and the polarity is called ADDITIVE.

Pole-Mounted Instrument Transformers

Instrument transformers were discussed earlier in this chapter, in the section on Switchboards and Distribution Panels. They are also used in municipal systems, and in cases where current is purchased from outside companies. In such cases, they are mounted on poles, in the same way as distribution transformers.

You will use pole-mounted instrument transformers at advanced bases only in the unlikely event that it will become necessary to measure current consumption at some point, or on some circuit.

QUIZ

1. Establishing a central power station as soon as possible at an advanced base, in place of having generators at points where power is needed, insures
   (a) steady supply of power at all points
   (b) savings in manpower
   (c) protection of electrical equipment from weather
   (d) all of the above

2. What name is given to the distribution system in which each feeder is made up of 3 wires?

3. What 3 factors are necessary if a generator is to produce high voltages?

4. In most a-c generators, the field windings are placed on the
   (a) armature
   (b) commutator
   (c) rotor
   (d) stator

5. What is the standard formula for determining the frequency of an a-c generator?

6. How are types of d-c generators distinguished?

7. A compound generator is one that has
   (a) another generator tied to the same bus
   (b) a series field added to a shunt generator
   (c) a constant armature voltage
   (d) a fluctuating terminal voltage

8. What 3 factors require careful consideration when power station generators are being installed?

9. Where is the voltage output from a generator first delivered? Controlled?

10. In a 3-phase type of generator, what is the setting of the stator coils?

11. In an a-c generator with stator coils delta connected, the voltage between any two lines is
    (a) the sum of the voltages across all three coils
    (b) the vector sum of the voltages across two coils
    (c) the rated voltage of the generator
    (d) all of the above

12. In a generator with Y-connected stator coils, the voltage between any hot line and the neutral line is the
    (a) rated voltage of the generator
    (b) equivalent of the voltage developed across any two coils
    (c) sum of the voltages across all three coils
    (d) vector sum of the voltages across two coils

13. What is the simplest way of arranging for a determination of phase sequence?

14. The term "switchgear" is used to identify the equipment that includes
    (a) only the equipment necessary for starting the prime mover
    (b) only the necessary tie-up between prime mover and generator unit
    (c) all voltage regulating equipment
    (d) individual generator switchboards and a panel for control

15. What is the purpose of the elapsed time meter?

16. When the voltage regulator switch is in the OFF position, is it possible to adjust generator output voltage?

17. What is the function of an a-c wattmeter?

18. Instrument transformers are necessary on the switchboards of most generators because
    (a) the voltages generated would render the switchboard meters and relays inaccurate
    (b) they can be used to step up the bus voltage, if necessary
    (c) they can be used to step up the voltage to feeder lines
    (d) the currents fed to the feeder lines are so high that they might open the built-in circuit breakers

19. What determines the current through the primary of a current transformer?

20. What determines the current through a voltage transformer?

21. Why is it important to have a grounding plan for any switchgear unit?

22. When are underground cables used at an advanced base, in preference to overhead systems?

23. What is the purpose of the 45-degree roof cut at the top of line-carrying poles?

24. Distance between poles in an overhead power system depends upon the
    (a) nature of the wood from which the poles are made
    (b) nature of the terrain
    (c) curvature of the pole
    (d) voltages to be carried by the wires

25. How do the gains face in an overhead system?

26. When are double crossarms used on a pole?

27. Vertical racks, formed by spool insulators held in place by a vertical rod, are used to carry
    (a) high voltage circuits
    (b) secondary voltages
    (c) combinations of power wires and telegraph wires
    (d) guy wires

28. What is the danger in stretching the wires in an overhead system too tight?

29. What are the 3 factors that determine the amount of sag?

30. What is the probable result of moisture in an underground cable system?

31. What is the function of a distribution transformer?

32. What is the advantage of the 2 secondary windings on a single-phase distribution transformer?

33. For transformers with primary and secondary voltages of less than 600 volts, heat is usually removed by
    (a) lightning arresters
    (b) protective gaps
    (c) natural circulation of air around core and case
    (d) oil, askarel, or similar insulating liquid

34. How does power output of the secondary coil of a transformer compare with power input to the primary coil?

35. How is the power factor of a transformer computed?

CHAPTER 7

OPERATION OF A GENERATING STATION

Once the central power station has been established, the various base activities should be able to count on a continuous and adequate flow of electric current, to meet the needs of the living and working spaces. The Construction Electrician who has worked on the installation of the distribution system will have a good working knowledge of this system as a whole; but he needs also a thorough understanding of how to operate and maintain the station equipment.

Complete knowledge of station equipment can be gained from three sources, none of which is sufficient in itself, but which together should provide all the information that you can possibly require for satisfactory operation and maintenance of the generating plant. These three sources are: (1) the general operating and maintenance procedures given in this chapter; (2) the electrical plans and diagrams relating to the generators, switchgear, cables, and other electric equipment; and (3) the specific instructions given in the manual furnished with each piece of equipment.

CHECKOUT PROCEDURE FOR AN A-C GENERATOR

Connecting the electric plant to a deenergized bus requires (1) starting the prime mover, and bringing it up to rated speed; and (2) operating the various controls mounted on the swichboard, so as to bring the power onto the bus.

Ordinarily, operation of the diesel engine or other prime mover is not your responsibility, except in the case of diesels that drive portable generators up to 75 kilowatt capacity. In every case, however, you should know the rated speed of prime mover necessary to produce the required voltage output.

The diesel will probably produce the 60-cycle voltage output required at most bases when ENGINE speed is 600 rpm. When the indicator gage shows a reading of 600 rpm, therefore, you should be ready to operate the switchboard controls.

The requirement for CE 3 to be competent to start diesel engines that drive portable generators is not included in the Qualifications for Advancement in Rating, in appendix III of this training course, but is a qualification recently decided upon at the Bureau level, and will be included in later revisions of NavPers 18068.

The following instructions for starting a diesel engine are general ones. If there is a manufacturer's instruction book for the equipment in your plant, follow the specific instructions given there, if they vary in any way from the ones included in this section.

The gage and control instruments mounted on the panel board of a diesel engine carry identifying titles that are self-explanatory. The engine control marked STARTING AIR LEVER controls the valve that admits starting air to the engine cylinders. The ENGINE OPERATING LEVER controls engine speed while starting, stopping, or under emergency control. The SPEED CONTROL KNOB controls the engine speed through the governor.

Figure 7-1 gives a general view of the controls and gages on a diesel engine. Figure 7-2 shows a close-up of the ENGINE OPERATING LEVER, so that you are able to distinguish its component parts.

The normal condition, in starting the engine, is to have the governor inoperative, so that the operator can control engine speed by moving the handle of the engine operating lever. At this stage, the pawl-actuating lever must be in a position where it points toward the engine operator.

With the pawl-actuating lever turned away from the operator, and the handle of the engine operating lever latched in the GOV. RUN position, the governor has complete control of engine speed. This is the normal condition after the engine has been started.

The latch lever is connected to a latch which holds the handle of the engine operating lever at the exact spot to which it is set. When you grasp the operating lever handle, the latch lever

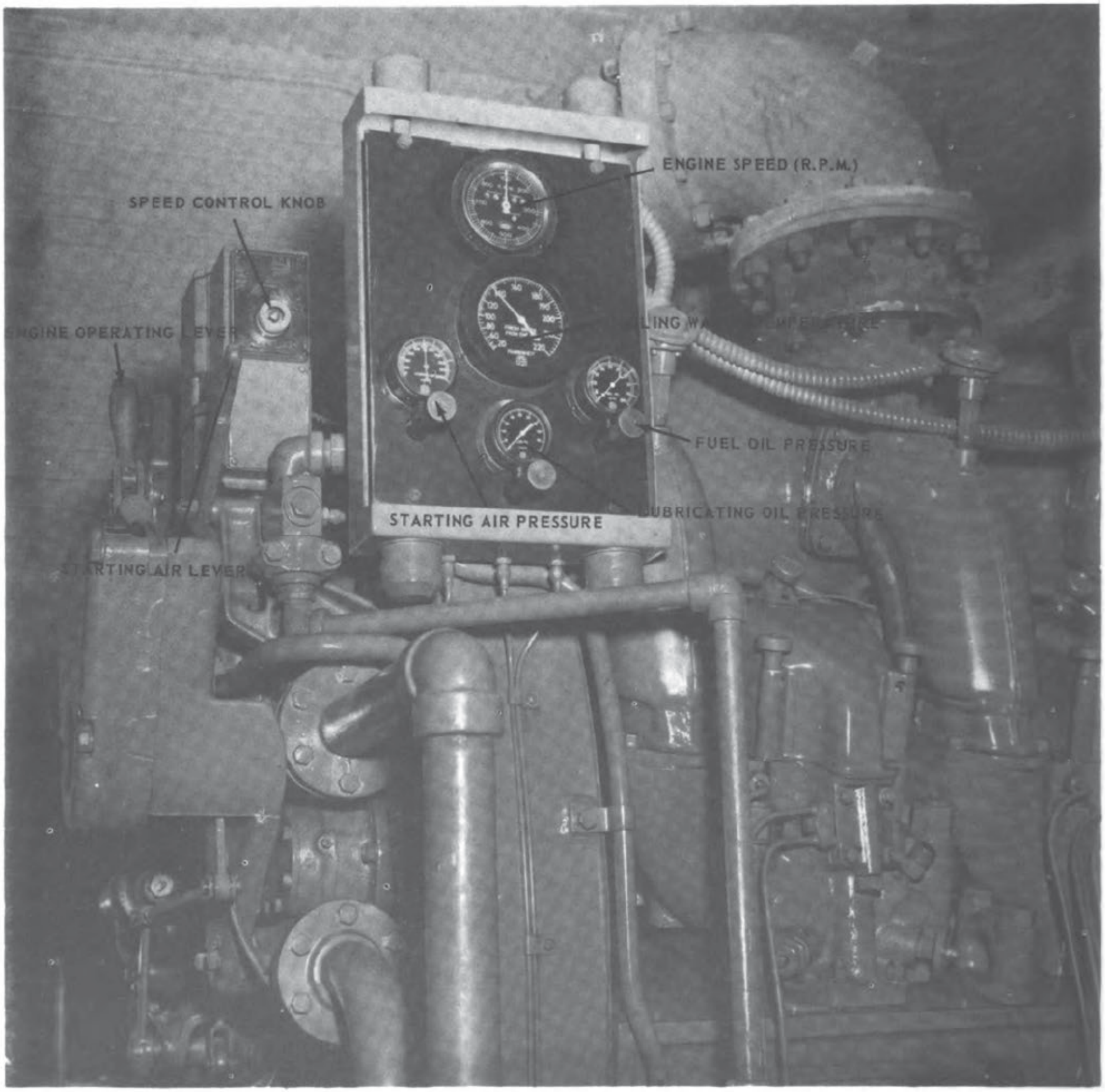


Figure 7-1.—Diesel engine controls and gages.

is near enough to be conveniently controlled by the fingers of that hand.

To control speed adjustment when you are operating the engine under emergency or manual control, use the vernier knob.

Before you start a diesel engine, make sure that the circuit breaker and the field switch on the generator switchboard are in the OFF position. Then grasp the operating lever handle with one hand, the starting air lever with the other hand, and proceed according to the following steps:

1. Set the pawl-actuating lever for manual control, and latch the engine operating lever in the INJ. FULL position.

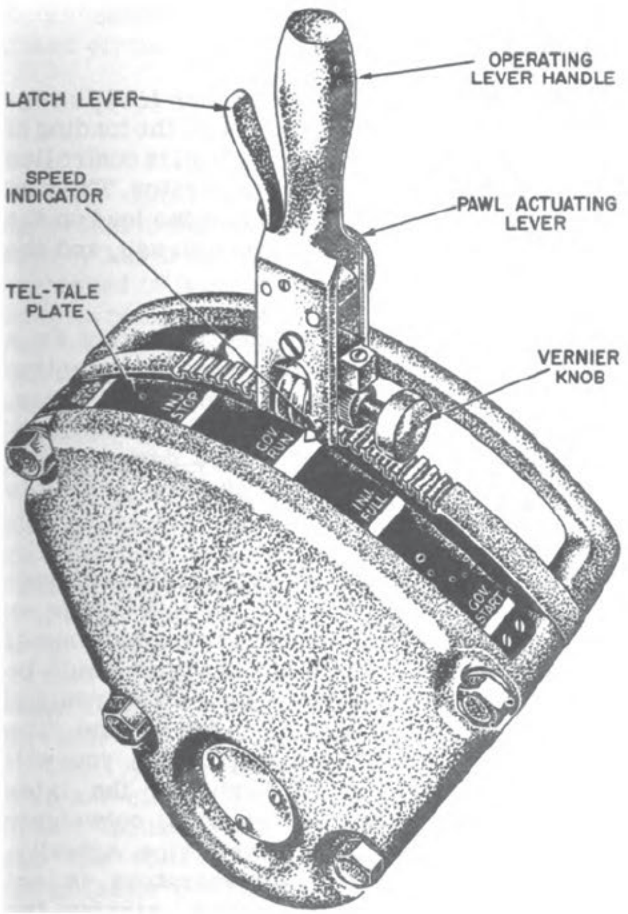


Figure 7-2.—Details of the engine operating lever.

2. Pull down on the starting air lever, to admit air to the engine cylinders. Release the starting air lever when the engine fires, which should be within 10 seconds.

3. Check the lubricating oil pressure gage. If pressure is not indicated on the gage within 10 seconds, stop the engine.

4. Give the governor full control of engine speed, by releasing the pawl-actuating lever, and latching the engine operating lever in the GOV. RUN position.

5. Check the rpm indicator gage for engine speed. If your plant must run at a rated speed of 600 rpm in order to produce a 60-cycle voltage output, and the indicator gage does not read 600, turn the speed control knob until the dial pointer reads 600 rpm.

6. Check the lubricating oil gage for proper oil pressure.

7. Check the fuel oil gage for proper fuel pressure.

8. Check the temperature gage for proper temperature of the circulating water.

At this point, you are ready to turn your attention to the controls on the generator switchboard.

Switchboard Controls

The switchboard instruments should include an indicating wattmeter, to save the necessity of multiplying readings from ammeter and voltmeter, in order to determine power. If records must be kept of the efficiency of the generator, a watt-hour meter is necessary, also.

Remember that the voltmeter measures the voltage of the bus, whether it be connected to one or more generators. Ammeters should be in one wire from each generator; if only one ammeter is available for measuring three-phase current, the ammeter will have to be swtiched to the different phases.

A group of lamps connected across the bus, and with a center point grounded, provides a practical means of detecting accidental grounds.

Placing on the Line

As you prepare to put the generator on the line, make sure that you know the location of the various switchboard controls, so that you can operate them smoothly and in proper sequence. The checkout procedure consists of the following steps:

1. Check to see that the voltage regulator switch is in OFF (or MANUAL CONTROL) position; and that the voltmeter switch is set to permit the a-c voltmeter to indicate line voltage in one phase, when the voltmeter is in parallel with another phase or the neutral line.

2. Turn the handle of the exciter field rheostat clockwise as far as it will go, so as to put maximum resistance into the shunt field of the exciter.

3. Throw the field switch to the ON position, to make the exciter's voltage available to the generator field. At the same time, watch the a-c voltmeter, to see that it records a low reading.

4. Turn the handle of the exciter field rheostat in the counterclockwise direction, to decrease resistance in the exciter field, and increase excitation voltage and excitation current

in the generator field winding. This will result in an increased output voltage. Manually adjust the voltage, while watching the a-c voltmeter, until the rated voltage (usually 4160 volts) is reached.

5. Check the frequency reading on the frequency meter. Using the governor motor control switch, raise or lower the speed of the prime mover, until you obtain normal frequency (60 cycles).

6. Turn the voltage regulator switch to the ON or AUTOMATIC position, so as to place the voltage regulator in control. Then check the a-c voltmeter to see if the voltage reading has varied from the rated value. If it has, adjust the voltage regulator rheostat until normal voltage is indicated by the voltmeter reading.

7. Release the interlock on the circuit breaker, and close the generator circuit breaker. This energizes the bus. With the generator now connected to the external circuit, the a-c ammeter indicates the current drawn by the load.

8. Use the ammeter switch to check the current in each phase. Recheck the voltage across each phase.

CHECKOUT PROCEDURE FOR THE D-C GENERATOR

The d-c generator is fairly simple to operate. You should take a look, from time to time, at the voltmeter, to make sure that rated voltage is being maintained. The load on the generator should be recorded periodically, and precautions taken against heavy overloads, since the prime mover is limited in power. Remember that the speed of the prime mover controls the voltage output of the d-c generator. The speed of the prime mover itself is regulated by its governor.

The generator should be able to withstand a 50-percent overload for at least 2 hours, without damage to the equipment. You will find it a safe rule, however, to limit any overload that must be carried for a long period of time to not more than 15 percent of rated load.

LOADING

For carrying heavy loads, generators may be tied together and operated in parallel. However, since the electrical equipment provided for advanced bases usually includes only one small d-c generator, your experience with paralleling generators will be confined to the synchronizing of a-c generators.

Unlike the d-c generator, where load is controlled by varying the field current, the loading of a-c generators operating in parallel is controlled by changing the speed of the generator. The load on a single generator depends on the load on the feeders, the number of feeders in use, and the length of feeder lines.

On small generators, each operating as a separate unit, some type of overload protection is provided in the terminal leads. The fuses, circuit breakers, relays, solenoids, and so forth that serve as circuit protective devices have already been described in chapter 2 of this training course.

When a-c generators are operating in parallel, these devices are not used. If a fuse or circuit breaker were to open to protect one of the units against overload, the result would be that the unit would have to be resynchronized with the other generator(s) in the system. The difficulties in resynchronizing (which you will understand after you have studied the later section, Synchronizing Alternators) outweights the advantages of the protective device. Actually, the load on paralled a-c generators is not equalized; the generator which carries the heavier load is slightly advanced in phase, in relation to the other generator. However, for all PRACTICAL purposes, the load is balanced.

POWER FACTOR

In theory, the power factor of a circuit containing only resistance is defined as the product of volts and amperes; but EFFECTIVE power is indicated by the reading taken from the wattmeter. Effective power is always a little less than apparent (or theoretical) power. So when we speak of the power factor of a circuit, we mean the ratio between effective and apparent power.

Power (the rate of doing work) is always measured in watts (or in kilowatts). Theoretical power is equal to the product of amperes and volts; by reading the wattmeter (actual power) and dividing this figure by the product of the readings from voltmeter and ammeter, you get the ratio known as power factor.

To determine the power factor in a single phase circuit, use the following formula:

$$P.\ F. = \frac{\text{watts}}{\text{volts} \cdot \text{amperes}}$$

This ratio is enough for explaining the difference between effective power and apparent power, but it is of no practical service if you are asked to improve the power factor. Knowing how to compute the power factor will not help you to raise the reading of the wattmeter. You must know WHY the wattmeter does not give the same result as the product of the readings from voltmeter and ammeter; and you must know HOW you can correct the power factor.

The power factor of an a-c load indicates what portion of the total power made available for that load is actually consumed by the load. Basically, the power factor depends upon the ratio of magnetizing current to power current. The power factor is low when a large part of total current is magnetizing current, and it is high when a large part of total current is power current.

The type of electrical machinery connected to an a-c circuit will have a lot to do with power factor. Induction motors, in which the current lags the voltage, are the main source of low power factor conditions.

The power factor of a load can be improved by connecting additional electrical apparatus into the circuit, to supply a capacitive reactive power that will offset the lag caused by the inductive load.

Synchronizing Alternators

Load power demand may often reach a point where it cannot be handled by the capacity of one generator. It will then be necessary to add the output of another generator to the bus. This CANNOT be done simply by starting up the engine of the reserve generator, and then throwing the main switch. Three very important factors must be taken into account: (1) incoming generator voltage must be approximately equal to bus voltage; (2) incoming generator voltage must have the same frequency as bus voltage; and (3) incoming generator voltage must be in phase with the voltage on the bus.

To adjust electrical speed, or frequency, you must adjust the governor of the prime mover. To bring the incoming generator into phase with the voltage on the bus, you will probably use a system of synchronizing lamps. Watch the voltmeters on the two units until they read the same. The purpose of synchronizing frequency and speed is to ensure that the potential difference between the CORRESPONDING terminals of the two generators will be zero.

Methods

There are two methods by which lamps are used as a means of synchronizing alternators; the first is known as the all-dark synchronizing method, and the second as the one-dark-and-two-bright synchronizing method. It is also possible to use the synchroscope, described in chapter 5 of this training course.

In the all-dark method, a bank of lamps is connected across each pole of the switch that connects the generator to the bus. The bus is already live from another generator or system. The lamps should have a voltage rating 15 percent higher than the generator terminal voltage. If the lamps brighten and dim together, the units are in phase. If they brighten and dim in sequence, the phase rotation of the two units is opposite, and one phase must be reversed. Figure 7-3 represents the arrangement of lamps in this method.

The lamps flicker at a frequency equal to the DIFFERENCE in frequency between the two machines. As the machines approach equal frequency, the flicker slows down. When the lamps are dark, the switch can be closed, and the generator placed in parallel with the bus.

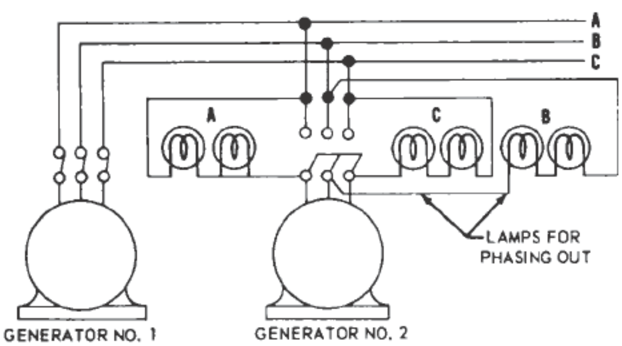


Figure 7-3.—The all-dark synchronizing method.

The one-dark-and-two-bright method is a more sensitive method, and is used for large, high-speed generators. The arrangement of the lamps in this method is shown in figure 7-4. When lamps A and B are bright, and C is dark, the unit is in phase. Since one of the two bright lamps increases in brilliancy while the other decreases in brilliancy, the instant of synchronism is when they match in brilliancy. The sequence of brightness of the lamps indicates whether the incoming machine is fast or slow. It is standard practice to close the generator switch when the incoming machine is gaining speed slowly, and is just below synchronous speed.

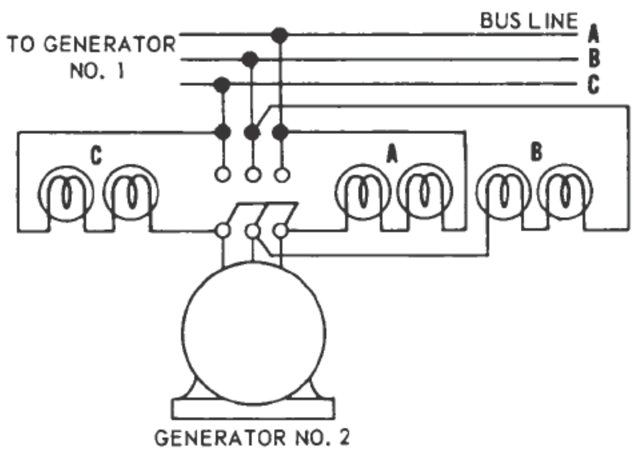


Figure 7-4.—One-dark-and-two-bright synchronizing method.

Procedures

The sequence of operations for paralleling two alternators is as follows:

1. After the prime mover has been started, bring the incoming generator up to normal speed and voltage, under the control of the voltage regulator.

2. Perform, in order, the steps listed as 1 through 6 in the earlier section, Checkout Procedure for an A-C Generator.

3. Compare the bus voltmeter reading with that on the incoming generator voltmeter. If they are not the same, adjust the voltage regulator rheostat of the incoming generator until the incoming generator voltage is equal to the bus voltage. This is an important step since unequal voltages will cause circulating currents to exist between the paralleled generators.

4. Compare the frequency of the incoming generator with that of the bus and adjust to correspond by means of the incoming generator's governor motor-control switch.

5. Turn the synchronizing switch to the ON position. The synchroscope will rotate in one direction or the other. If the switchboard is also equipped with synchronizing lamps, they will increase and decrease in brilliancy.

6. Use the governor motor control switch to adjust the speed of the incoming generator until it is operating at approximately the same frequency as the bus voltage. This will be indicated by the synchroscope rotating slowly in the FAST direction and the synchronizing lamps slowly increasing and decreasing in brilliancy.

7. Make sure that the voltages of the bus and incoming generator are the same. Then, JUST BEFORE the synchroscope pointer passes through the zero position (pointing vertically upward), close the incoming generator's breaker. When synchronizing lamps are used, the breaker should be closed JUST BEFORE the midpoint of the dark period of the lamps is reached.

After the incoming generator has been connected to the bus, there are two additional adjustments that must be made. One adjustment ensures that each generator is carrying its share of the kilowatt load. The other adjustment ensures that each generator is operating with the same power factor—that is, each generator is producing its share of wattless current or reactive kv-a. The division of kilowatt load between a-c generators operating in parallel depends on the relative setting of their engine governors, while the amount of reactive kv-a they supply depends on the relative setting of their voltage regulators. Therefore, to adjust the generators for parallel operation:

8. Turn the governor motor control switches until the wattmeters of each generator have equal readings (if the generators have the same rating) or the load is divided in proportion to the generator ratings (if the generator ratings differ from each other). The load is increased on the lightly loaded generator by turning its governor motor switch in the direction that increases engine speed, while the load is decreased on the heavily loaded generator by turning its governor motor control switch in the direction that decreases engine speed. These adjustments should be made simultaneously in order to maintain a constant frequency.

9. Turn the voltage regulator rheostat of each generator until their power factor meters read the same (this indicates that each generator

is sharing the burden of reactive kv-a proportionately). If the switchboard is not equipped with power factor meters, the a-c ammeter of each generator can be used. Proper adjustment has been made when the a-c ammeters show equal currents if the generators have the same ratings; or currents proportional to the generator ratings if the generators have different ratings. The direction in which you turn the voltage regulator rheostat of each generator depends on the readings of the generator's power factor meter or a-c ammeter before the adjustment is made. The voltage should be decreased on the generator carrying the largest lagging current (lowest power factor) and increased on the generator carrying the least lagging current (highest power factor).

Before you close the main switch of the incoming generator, make sure that:

1. Output voltage of the incoming generator is equal to bus voltage.
2. Frequency of the incoming generator is equal to that on the bus line.
3. Voltage of the incoming generator is in phase with bus voltage.

After throwing the main switch, watch the a-c ammeters of each of the generating units, to be sure that they read an equal amount. Unequal readings mean that one generator is doing more work than the other. You can divide the load more evenly by increasing the speed of the generator that has the lower current reading. Adjust the throttle knob until both a-c ammeters show the same reading.

Securing the Generators

When a SINGLE generator, connected alone to a bus, is to be taken out of operation, it should be secured in the order indicated in the following steps:

1. Open the feeder breakers, in order to reduce the generator load as much as practicable.
2. Trip the generator circuit breaker.
3. Turn the voltage regulator switch to the OFF or MANUAL position.
4. Turn the handle of the exciter field rheostat clockwise, as far as it will go; this cuts out all resistance in the exciter field.
5. Open the field switch slowly. Slow movement of the switch reduces the danger of generating a high induced voltage in the field circuit; if the field discharge resistors were inoperative, a high voltage could break down the insulation.
6. Stop the prime mover by moving the operating lever to the GOVERNOR STOP position.

It may be necessary to secure a generator that has been operating in parallel with another unit. Usually, parallel operation is used to take care of peak loads, and when the peak has passed, one generator is enough. Sometimes, a generator may give signs of erratic operation, and it is advisable to cut it out of parallel plant operation, and depend upon only one generator for service.

Before you remove the generator power from the bus, it is very important to shift all the kilowatt load to the generator, or generators, that are to remain on the line. This shift of kilowatt load is accomplished by turning the governor motor control switch of the generator to be secured to LOWER, and the governor motor control switches of the remaining generators to RAISE. The wattmeters on the switchboard will indicate how the shift is progressing, and when it is completed.

Once the load has been shifted from the generator to be secured, trip the generator circuit breaker, and then secure the unit as you would any single generator.

Standing the Generator Watch

A constant, around-the-clock attention must be given to the generators at a central power station that is required to supply a continuous and adequate amount of power. The 24-hour period is divided into an even number of watches; the number depends, of course, upon the personnel available for this type of duty.

At most stations, 6-hour watches are the common practice. An 8-hour watch schedule does not ordinarily work a hardship, but any watches of more than 8 hours should be avoided unless emergency conditions make them necessary.

If your generator watch calls for starting up and operating a unit, the following list of operations will be a useful guide:

BEFORE STARTING:

1. See that the fuel tank is filled with diesel fuel oil.
2. Fill the gasoline tank with gasoline (on diesel engines started by gas).
3. Fill the radiator with water.
4. Check crankcase oil. Add oil if required.

5. Set the main switch and field switch to their OFF positions.

DURING OPERATION:

1. Keep a check on the oil pressure gage.
2. Keep a check on the voltage across each leg of the line.
3. Watch the frequency meter for proper frequency output.
4. Keep a check on the amperage in each leg of the line.
5. Keep an eye on the charging ammeter for correct charging of the battery.
6. Watch the water temperature gage to see that the engine is not overheating.

AFTER SHUTDOWN:

1. Fill gasoline and fuel tanks.
2. Fill radiator and check oil level.

The duties of the man on watch fall into three major groups: operating station equipment, maintaining station equipment, and keeping a daily operating log. In a sense, this third duty is a definite part of the first two, and will be discussed in the following section.

To keep the station equipment operating in a satisfactory manner, you must know the system, and the operating procedures. You must know when any irregularity occurs, its probable cause, and the quickest and best way to remedy it.

A point not always wholly understood by new men is the need for keeping the spaces in the power station clean and orderly. This is not only a protection for the equipment, but it is also a safety measure. Fewer accidents to equipment and to personnel occur when cleanliness and order are practiced. And even minor accidents to machinery or slight injuries that remove a man from the active duty list, may limit the efficiency with which the power station meets the needs of the base.

Keep all tools in their proper places, so that you can find them readily when they are needed, and so that they will not be a hazard to the men on watch. Keep oily waste in a separate container from clean waste, and reduce fire hazard by emptying oily waste at least once a day. Keep the floor swept down, and if oil or grease is spilled or tracked about, clean it up at once. Make sure that all auxiliary equipment is in good condition, and in its proper place, so that there will be no delays if it must be brought into service.

The following list of rules will be useful to you when you are standing a watch. You must not conclude, however, that these rules are enough in themselves; in addition, you must follow the general instructions already given, and you must be aware of any special situations or conditions that may arise in connection with your particular power plant.

1. Allow no unauthorized personnel to loiter about your station.
2. Allow no unauthorized personnel to go behind main switchboards.
3. Make frequent inspections of all running generators.
4. Never replace a blown fuse with one of a higher rating.
5. Do not allow emery cloth or steel wool to be used near any electrical equipment.
6. Watch the switchboard instruments for any indication of abnormal conditions.
7. Keep frequency and voltage at their correct values. A variation from either will affect, to some extent at least, the operation of the bases's electrical equipment. This is especially true of such equipment as teletypewriters or electric clocks. To maintain reasonably constant frequency, an electric clock and an accurate mechanical clock should be installed together at the powerhouse so that the operators can keep the clocks in time with each other.
8. USE JUDGMENT WHEN RECLOSING CIRCUIT BREAKERS AFTER THEY HAVE TRIPPED AUTOMATICALLY. Generally the cause should be investigated if the circuit breaker trips immediately after the first reclosure. However, reclosing of the breaker the second time may be warranted if immediate restoration of power is necessary and the interrupting disturbance when the breaker tripped was not excessive. In this respect, it should be kept in mind that repeated closing and tripping may result in damage to the circuit breaker and thus increase the repair or replacement work.
9. Don't start a plant unless all its switches and breakers are open and all external resistance is in the exciter field circuit.
10. Don't operate generators at continuous overload. Record the size and length of time of the overload in the log together with any unusual conditions or temperatures observed.

11. Don't continue to operate a machine in which there is vibration until the cause is found and corrected. Record in log.
12. Keep the log sheets up to date.
13. Observe all safety rules posted in your station.

Operational Logs

The station log serves as a basis for determining when various equipment units require maintenance or replacement. A series of logs can often pinpoint signs of breakdown in various parts of the station equipment, when that breakdown is taking place so slowly that on any one day it is not obvious as a problem in maintenance or repair.

With so much complex equipment working together to produce heat, light, and power for the base, it is extremely important that each item of this equipment be operating satisfactorily. A well-kept log should alert a well-trained man to the first signs that something is going wrong in the power plant.

Logs are made up on the various stations, so that there is no standard form that the CEP must follow in his particular plant. The main thing is that the log cover the hourly performance not only of the generators, but of the numerous indicating and controlling devices.

Figure 7-5 illustrates one type of log that may be kept on the generator units of a power plant. However, this is only a suggestion, and does not contain a complete record of the types of information that are usually kept. On your particular station, you will know from the established log just what entries you should make, and on what equipment items.

MAINTENANCE AND REPAIRS

The maintenance done on site at a central power plant is the type best described as preventive maintenace. Such repairs as the rewinding of armatures and field coils is done at the shop; portable generators requiring major repairs are sent to the shop; and motors, measuring devices, controllers, and so forth that fail to operate satisfactorily are best sent to the shop for complete overhaul and repair.

As far as grounds and shorts in circuits or in equipment is concerned, the preceding chapters have already supplied you with enough information. Other routine maintenance includes repairing loose or oil-soaked leads; inspecting bushings, and repairing or rebuilding as necessary; replacing insulating oil in oil-immersed transformers and switches, and checking for any indication of water in the oil; and making sure that all parts of the electrical system or equipment are kept clean, and are operated according to approved procedures.

Most of the generating equipment at the station will give little trouble, if you maintain schedules for inspection and maintenance in accordance with the manufacturers' manuals supplied with the equipment. The log kept on generator action, plus the records of the check-ups made after every 100 hours of operation, will give warning of any condition that could lead to a major breakdown in service.

Switchgear

At least once a year, a check should be made of the switchgear component, with careful attention being given to the following factors:

1. General cleaning of the component parts, and of the switchboard panel.

The front panels of dead-front switchboards can be wiped off with a dry cloth; the metal-clad switchgear can be opened, and inspected for surface cleanliness. Before any work is done on live parts, deenergize the switchboard. Wipe dust from the bus bars and the insulating material.

2. Inspect electrical connections and mechanical fastenings.

Do not limit this check to a sight inspection, but touch and shake the various parts to make sure that all connections are tight, and all mechanical parts free to function properly. Pay special attention to the bolted joints of the bus bar, since a loose joint can cause overheating.

3. Examine all meters and instruments mounted on the switchgear panels.

Look for cracked or broken glass, or signs of damage to the cases. Adjust the pointer of each instrument, so that it reads zero when the instrument is not energized.

4. Examine all indicating lamps, to make sure that none are too weak, or burned out.

5. Inspect all instrument transformers mounted on the switchboard.

Good condition of instrument transformers requires that all primary and secondary connections be tight, and grounding connections

SUGGESTED FORM OF PLANT OPERATION LOG

Date	Time	UNIT NO 1785			UNIT NO 942			UNIT NO 3465			REMARKS
		Elapsed Time Meter	Volts	Amperes	Elapsed Time Meter	Volts	Amperes	Elapsed Time Meter	Volts	Amperes	
4/17/59	1600	195.0	220	58	302.0	220	52	934.0	220	27	Started up
"	1730	196.5									added 2qts oil to #1785
"	2100	200.0	221	54	307.0	221	49				Shut down #3465

Figure 7-5.—Meter log.

intact. Potential transformer fuses must make firm contact in their clips.

6. Check the condition of all rheostat mechanisms.

Replace broken or burned-out resistors; if no replacements are available, make temporary repairs by bridging the burned-out sections. Check to see that there is nothing to block the ventilation of rheostats and resistors.

7. Test the operation of switchgear position-changing mechanisms, such as the lowering and raising mechanisms, and the pullout devices of the circuit breakers used in metal-clad switchgear.

Circuit Breakers

A yearly inspection should also be made of all power circuit breakers, except the oil circuit breakers, which should be inspected at 6-month intervals. A special inspection should be made after a circuit breaker has opened a heavy short-circuit. Also, circuit breakers that are kept for a long period of time in either open or closed position should be tested occasionally, to make sure that they are in good operating condition.

Specific instructions on the maintenance and repair of the various types of power circuit breakers are available in the instruction manuals that accompany each switchgear unit. General procedures should include a check for cleanliness, for pitting, and for alinement, and a test of circuit breaker mechanisms. A schedule of inspection might be set up to cover the following points:

1. Remove any surface dirt, dust, or grease with a clean cloth moistened with a standard cleaning solution. Use a fine sandpaper to remove the black copper-oxide film that forms on copper contact surfaces. The slight discoloration on silver contacts is a normal film that will do no harm.

2. Inspect all silver and copper contacts for any sign of severe pitting or burning, since this type of wear can cause damage to other parts of the breaker.

Use sandpaper (but NEVER emery paper) to smooth down the contacts, but try to remove as

little material as possible, and keep the original shape of the contact surface. Where contacts are too severely pitted to repair, you will have to replace them; but do this in pairs, not singly.

3. While inspecting contacts for pitting, check for proper alinement. The contact surfaces should bear with a firm, uniform pressure.

4. Inspect circuit breaker mechanisms, to make sure that all parts are in good condition, and operating freely.

Look for signs of excessive wear or corrosion, and for any evidence of overheating in the pins, bearings, latches, and springs of these mechanisms.

Test the operation of trip shafts, toggle linkages, latches, and so forth. The test can be made by slowly opening and closing the circuit breaker manually. As you do this, make sure that the arcing contacts meet before and break after the main contacts.

Remove the arc chutes, and examine them for broken or damaged lining. If scale is present, do not remove it until you have consulted the instruction manual for that particular breaker. Some manufacturers recommend removal; others do not.

In any work performed on power circuit breakers, the utmost caution should be taken. The following safety rules should be observed:

1. Before you begin work on a circuit breaker, make sure that its control circuits are deenergized.

2. Switch the draw-out circuit breakers in metal-clad switchgear to the open position, and remove them from the circuit before any work is done on them.

3. Open all disconnecting switches ahead of fixed mounted circuit breakers before doing any work on the breakers. If there are no disconnecting switches in the system, you will have to deenergize the supply bus to the circuit breaker.

4. Make sure that all breaker studs and current-carrying parts are adequately grounded before you touch any part. Take precautions to see that this temporary grounding is maintained throughout the inspection period.

Insulated Bushings

The bushings—or insulators, as they are commonly called—on low voltage lines should be replaced as soon as they show signs of being defective. The bushings used on higher voltage lines (4160 volts or over) should be protected as far as possible; repairs on these bushings should be made in accordance with the instructions issued for the various types.

Figure 7-6 illustrates two types of bushing: the L-type and the S-type.

Failure of these bushings is often caused by a shrinkage of the inelastic compound, with the result that small cracks or pockets are formed. Weather conditions which cool the bushing rapidly will cause contraction of the metal parts; sooner or later, the cork in the top-cap assembly will crack.

Moisture drawn into the voids formed by contraction will follow cracks to the lowest point (at the mounting flange), and will attack the insulation. Breakdown may occur, sometimes because of a surge, but also because the moisture provides a continuous conductor between cap and bushing flange.

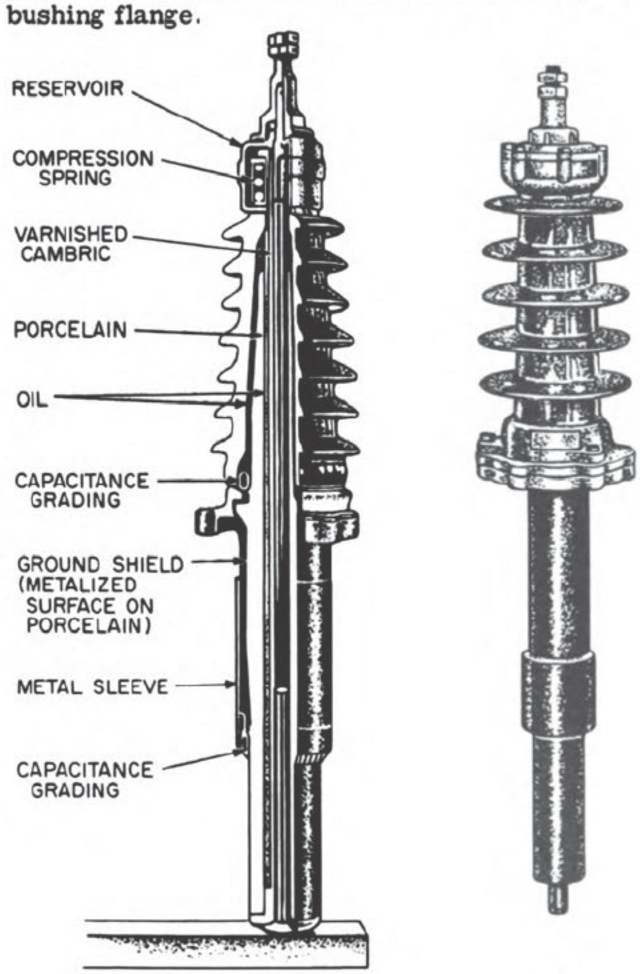


Figure 7-6.—Bushings: A, L type; B, S type, with 2-piece cap and 2-piece support flange.

If the moisture forms a path between cap and bushing flange, the steam generated by the arc may explode and destroy the porcelain casing. This would leave the conductor stem, insulated only by treated paper, open to the elements. If this should happen, the bushing will have to be replaced.

Bushings may be on oil circuit breakers, or on transformers. Those on transformers may be the draw-lead type, or they may be the type with detachable bottom terminal. In order to obtain the correct replacements, you will have to check the following items:

1. The nameplate: rating, voltage, and amperes should be the same.
2. Mounting flange: bolt circle diameter, number and size of holes, and gasket recess should be the same.
3. Stem diameter: for oil circuit breaker bushings, and transformer bushings with detachable bottom terminal, the outside diameter and the number of threads per inch at the lower end of the stem should be the same. For draw-lead type bushings, the inside diameter of the stem must be the same as that of the bushing being replaced.
4. Stem length under flange: dimensions from the face of the mounting flange to the lower end of the stem should be the same for oil circuit breaker bushings, and for transformer bushings with detachable bottom terminal. For transformer bushings of the draw-lead type, this dimension may vary as much as an inch.
5. Ground shield: minimum oil level should be 1/2 inch above the end of the grounded metal.
6. Lower terminal: on oil circuit breaker bushings, where a terminal fitting is applied, it should be the same. On bushings with detachable bottom terminal, the lower end of the stem should accommodate the lug or fitting on the transformer lead.

Upper terminal caps vary, so there is no need of checking this item in ordering replacements. The length of the upper portion of any of these types of bushings may vary as much as two inches (plus or minus), but changes in connections can be made when the bushings are installed.

Trouble-Shooting

Experience at power distribution plants has indicated that the following trouble-shooting charts for d-c generators, a-c generators, switchgear equipment, and power circuit breakers provide the maintenance and repair information necessary for the practical operation of the power plant.

If the right attention is given to locating the electrical equipment, to operating conditions, to cleanliness, and to competent inspections, there should be a minimum of risk that serious breakdown will occur in an electric distribution system. Correct the smaller types of troubles as they become evident, using the trouble-shooting charts given here as guidelines.

Trouble-Shooting Chart—D-C Generators.

Trouble	Possible cause	Remedy
Failure to build up voltage.	Voltmeter not operating.	Use separate voltmeter to check output voltage. Replace defective meter.
	Open field resistor.	Repair or replace
	Open field circuit.	Check coils for open or loose connections. Tighten connections, or replace defective coils.
	Dirty commutator.	Clean or dress.
	Brushes not making proper contact.	Free brushes that are binding in holders. Replace and reseat worn brushes.
	Open ammeter shunt.	Replace ammeter and shunt.
	Grounded or shorted field coil.	Test, and repair or replace.
Sparking at brushes.	Overload.	Check meter reading against nameplate rating. Reduce load.
	Dirty brushes and commutator.	Clean.
	Brushes sticking in the holders.	Clean holders. Sand brushes.
	Insufficient brush pressure.	Adjust or replace tension springs.
	Field winding grounded, open, or short circuited.	Repair or replace defective coil or coils
	Open circuit in the armature.	Repair; or send armature to shop for replacement.
Field coils overheat.	Shorted or grounded coils.	Repair or replace.
	Poor ventilation.	Check for clogged air passages. Clean equipment, remove obstructions.
Armature overheats.	Overload.	Check meter readings against nameplate rating. Reduce load.
	Excessive brush pressure.	Adjust pressure or replace tension springs.
	Couplings not alined.	Aline units properly.
Output voltage too low.	Prime mover speed too low.	Adjust governor.
	Commutator dirty.	Clean. If film is too heavy, replace the complete set of brushes.
	Brushes not seated properly.	Run in with partial load; use brush-seating stone.
	Field resistor not properly adjusted.	Tighten connections and adjust shim.
	Reversed field coil or armature connection.	Check, and connect properly.
Output voltage too high.	Speed of prime mover too high.	Adjust governor on prime mover.
	Defective voltage regulator	Adjust or replace.

Trouble-Shooting Chart—A-C Generators.

Trouble	Possible cause	Remedy
Noisy operation.	Unbalanced load.	Balance the load
	Coupling loose or misalined.	Reline coupling and tighten.
	Vibration.	Tighten bolts.
	Improper air gap.	Check for bent shaft, for loose or worn bearings. Realine shaft; replace bearings.
Overheating.	Overload.	Check meter readings against nameplate rating. Reduce load.
	Unbalanced load.	Balance load.
	Open load-line fuses.	Replace fuse.
	Poor ventilation.	Clean, and remove any obstructions to ventilation.
	Rotor winding short circuited, open circuited, or grounded.	Check; replace defective coil or coils.
	Stator winding short circuited, open circuited, or grounded.	Check; replace defective coil or coils.
	Bearings.	Check for worn, loose, dry or overlubricated bearings. Replace worn or loose bearings, lubricate dry bearings, relieve over-lubrication.
Output voltage unsteady.	Poor commutation at sliprings.	Clean sliprings and brushes. Reseat brushes.
	Loose terminal connections.	Clean and tighten all connections and contacts.
	Maladjusted voltage regulator and speed governor.	Readjust speed governor and voltage regulator.
Output voltage too high.	Overspeeding.	Adjust speed-governing device.
	Overexcited.	Adjust voltage regulator.
	Delta-connected stator open on one leg.	Remake connection; repair or replace defective coil.
Frequency incorrect or fluctuating.	Speed incorrect or fluctuating.	Adjust speed-governing device.
	D-C excitation fluctuating.	Adjust tension in belt of exciter generator.

Trouble-Shooting Chart—Switchgear Equipments.

Trouble	Possible cause	Remedy
Meters fail to register.	Blown potential transformer fuse.	Renew blown fuses. (Repeated fuse failures call for investigation and correction of trouble.)
	Broken wires; faulty connections.	Replace wires; secure connections.
Meters inaccurate.	Zero adjustment off. Meter may be dirty or choked with dust accumulation; there may be magnetic particles adhearing to the magnets; meter may have faulty internal parts—cracked jewel, damaged coils, etc.	Readjust. Clean meter, or repair or replace faulty parts, and test and calibrate. Note.—Meters are precision instruments that require expert care. Only an instrumentman should be allowed to repair damaged mechanical movement. Testing and calibration should be carried out according to manufacturer's instructions.
Overheating of connections.	Increase of current due to additional load that is above normal current rating of bars or cables.	Increase the current-carrying capacity (increasing number or size of conductors) or remove additional load.
	Bolts and nuts loose in the connection joints.	Tighten.
Noises due to vibration of parts.	Loose bolts or nuts at connection joints.	Tighten (avoid too much pressure).
	Loose laminations in cores of transformers, reactors, etc.	Tighten loose nuts or core clamps.

Trouble-Shooting Chart—Power Circuit Breakers.

Trouble	Possible cause	Remedy
Overheating.	Contacts out of alinement and adjustment.	Line up and adjust contacts properly.
	Contacts burned and pitted.	Redress contacts if practical, or replace with new parts.
	Overloading (continuous or prolonged current in excess of breaker ratings).	Replace with breaker having adequate rating for the present or future load or arrange circuits so as to remove excess load.
	Loose connections or terminal connectors.	Tighten.
Failure to trip.	Lack of lubrication.	Lubricate mechanism.
	Mechanism out of adjustment.	Adjust all mechanical devices according to instruction book.
	Failure of latching device.	Examine surface of latch. If worn or corroded, it should be replaced.
	Damaged trip coil.	Replace damaged coil.

Trouble-Shooting Chart—Switchgear Equipments. (Continued)

Trouble	Possible cause	Remedy
	Blown fuse in control circuit	Replace blown fuse.
	Faulty connections in trip circuit.	Repair faulty wiring. See that all binding screws are tight.
	Damaged or dirty contacts on tripping device.	Dress or replace damaged contacts or clean dirty contacts.
Failure to close or to latch closed	Closing coil (of electrically operated breakers) burned out due to operator holding control switch closed too long.	Replace damaged coil and instruct operator in proper operating procedures.
	Mechanism binding or sticking.	Lubricate, or if necessary, adjust to specifications in breaker instruction book.
	Insufficient control voltage (of electrically operated breaker) caused by:	
	1. Too much drop in leads.	Install larger wires; improve contact at connections.
	2. On a-c control—poor regulation.	Install larger control transformer, check rectifier, and be sure it is delivering adeqaute d-c voltage.
	3. On d-c control—battery not fully charged or in poor condition.	Charge battery or repair or replace.
	Blown fuse in control circuit; faulty connection or broken wire in control circuit; damaged or dirty contacts in control switch (electrically operated breaker.)	Replace blown fuse; repair faulty connection or broken wire; dress or replace damaged contacts or clean dirty contacts in control switch.

QUIZ

1. What are the two major steps in starting an a-c generator?

2. The voltmeter on a switchboard measures the voltage of
   (a) a specified single generator in a parallel plant operation
   (b) the bus
   (c) the potential instrument transformer
   (d) none of the above

3. Turning the handle of the exciter field rheostat in the counterclockwise direction will
   (a) decrease excitation voltage in the field winding
   (b) put maximum resistance into the shunt field of the exciter
   (c) decrease resistance in the exciter field
   (d) lower the output voltage

4. The loading of a-c generators operating in parallel is controlled by
   (a) varying the field current
   (b) installing an equalizer
   (c) adjusting the voltage regulator rheostat
   (d) changing the generator speed

5. Why is a circuit breaker seldom used to protect against overload on generators operating in parallel?

6. What is the formula for computing effective power of an a-c generator?

7. What is actually indicated by the power factor of an a-c load?

8. Before an incoming generator can safely be paralleled with one already in service, what 3 conditions are necessary?

9. If the voltage of an incoming generator is not the same as that indicated on the bus voltmeter of the generator on the line, you can bring the two machines to equal voltage by adjusting
   (a) the synchronizing switch
   (b) the voltage regulator rheostat of the line generator
   (c) the voltage regulator rheostat of the incoming generator
   (d) none of the above

10. After you throw the main switch to parallel two generators, you should watch the a-c ammeters of both units, until you get what result?

11. The first step in securing a generator that has been operating as a single plant is to
    (a) stop the prime mover
    (b) turn the voltage regulator to OFF position
    (c) trip the generator circuit breaker
    (d) open the feeder breakers

12. Preliminary steps in securing a generator that has been operating in parallel include
    (a) moving the governor motor control switch to LOWER
    (b) moving the governor control switch of the remaining generator to RAISE
    (c) shifting the kilowatt load to the remaining generator
    (d) all of the above

13. What are the 3 overall responsibilities of the man standing a generator watch?

14. A regular check of all switchgear components should be made at least
    (a) once a year
    (b) once every 6 months
    (c) once every 3 months
    (d) monthly

15. What should you specially look for, in inspecting switchboard meters?

16. An inspection of oil circuit breakers should be made at least
    (a) once a year
    (b) every 6 months
    (c) every 3 months
    (d) monthly

17. What is the common cause of failure in bushings on high voltage lines?

18. Noisy operation of an a-c generator may be caused by
    (a) overload
    (b) unbalanced load
    (c) short-circuited rotor winding
    (d) poor commutation at sliprings.

19. Failure of a switchgear meter to register may be caused by
    (a) a blown fuse in the potential transformer
    (b) loose laminations in transformer core
    (c) an increase of current due to additional load
    (d) all of the above

CHAPTER 8

COMMUNICATIONS SYSTEMS

In the study of chapters 4 and 6 of this training manual, you have acquired a general knowledge of how wiring and cables are installed. In this chapter, you will learn something of open wire systems; the basic elements of local battery and common battery systems; the use of switchboards for multiline services; and the fundamentals of dial telephone systems, office intercommunications systems, and public address systems.

ADVANCED BASE TELEPHONE EQUIPMENT

One of the first requirements at an advanced base is establishing an adequate communications system. The equipment used at these Navy bases is very much the same as the equipment used by the Army Signal Corps, and consists primarily of field type switchboards, telephone sets, and field wire. The switchboards may be powered by local batteries, or by a central source of power. The field wire consists of a twisted pair of conductors that are individually insulated, but not provided with an overall covering.

This type of field wire is used throughout small systems; in large systems, it is used as distribution cable and drop wire. Ordinarily, field wire provides a talking range of from 15 to 20 miles, but this range can be extended by the use of loading coils or repeaters.

The components of a field telephone system are: the power source; the transmitter; the receiver; the transmission line or talking circuit; the ringer for signaling, and the signaling circuit; and the switch for closing and opening the talking circuit.

The power source may be a generator, a power line, a storage battery, or a simple dry cell. How cells and storage batteries provide electrical energy for a talking or a signaling circuit is described in the section, Circuits, later in this chapter.

Transmitter

The purpose of the transmitter is to convert sound waves introduced into the energized circuit into waves of electric current of corresponding waveform and frequency. When these electrical waves reach the receiver, they are reconverted into sound waves.

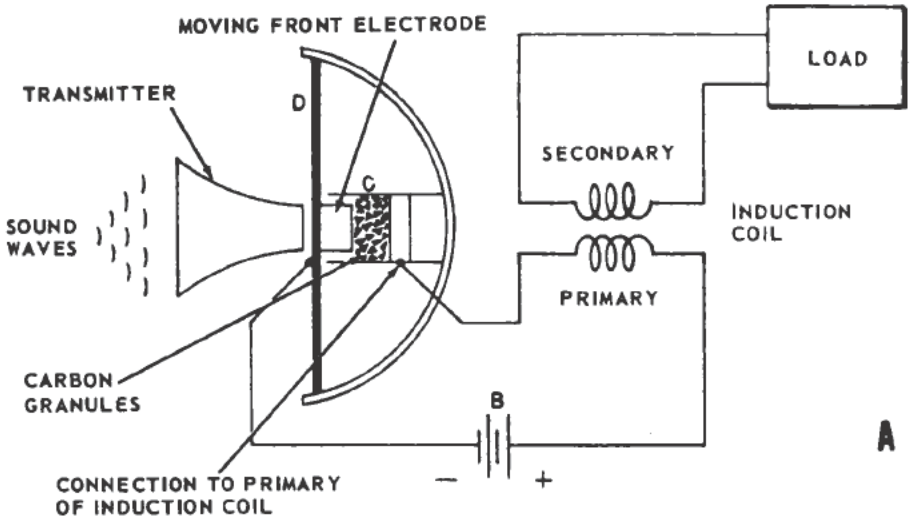
Energy losses during transmission over the wires would naturally cause the useful energy at the receiver end to be less than that of the initial energy of the sound waves. The circuit of the transmitter must be capable of amplifying the original energy of the sound waves, so that conversations may be held over long distances.

Various types of carbon transmitters in common use today provide this necessary increase in energy. The device used is an induction coil, which acts in much the same fashion as a transformer. The battery, the carbon, the diaphragm, and the induction coil compose the basic circuit, as illustrated in figure 8-1.

A bell-shaped chamber is packed with carbon granules, which have uniform contact with two gold-plated electrodes. The diaphragm is of flexible aluminum alloy, supported by paper spacers. The negative terminal of the battery connects with the diaphragm, which in turn rests against the chamber of carbon granules. The other side of the carbon chamber is connected with the primary of an induction coil. The return of the primary to positive terminal of the battery completes the circuit. You can readily follow this explanation on A of figure 8-1.

Sound waves entering the diaphragm cause it to vibrate, and the moving front electrode exerts a varying pressure on the carbon. As the state of compression of the granules varies, the resistance also varies; as compression increases, resistance decreases, and the current in the circuit increases.

For example, if the battery has an emf of 6 volts, and the carbon granules have a normal resistance of 300 ohms, the average value of



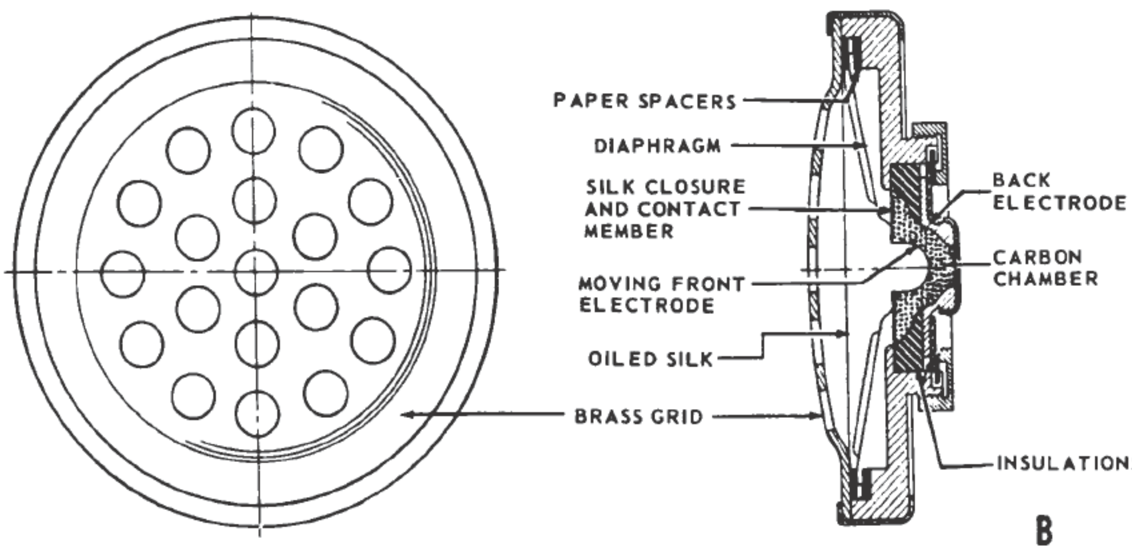


Figure 8-1.—A carbon transmitter: A, circuit; B, construction.

current flow will be 20 milliamperes. When the diaphragm is made to vibrate, by speaking into it, the compression on the carbon granules may decrease resistance to 200 ohms, and current will consequently increase to 30 milliamperes.

On recently developed transmitters, sound waves intended to actuate the diaphragm should strike it at right angles, and from a very short distance. If the sound originates too far from the instrument, it will enter the transmitter from both the front and the back of the diaphragm, and thus will equalize pressure on the granules. The effect of these distant sounds is practically zero. This type of transmitter has a decided value for military use, since it successfully cancels out background noises.

Receiver

The receiver reconverts the electrical waves to sound waves. You can guard against leakage of sound by holding the earpiece close to your ear.

The type of receivers are the moving conductor and the magnetic diaphragm as illustrated in figure 8-2. The diagrams in the figure indicate clearly the action on the diaphragm.

Both types are permanent magnet devices, but the moving conductor operates on the same principle as a meter. That is, as the current in the moving conductor (a coil of aluminum alloy attached to the diaphragm) varies, the magnetic field around the coil varies. As a result, the coil vibrates and causes the diaphragm to vibrate, and thus generate sounds of the same waveform and frequency as the current in the coil.

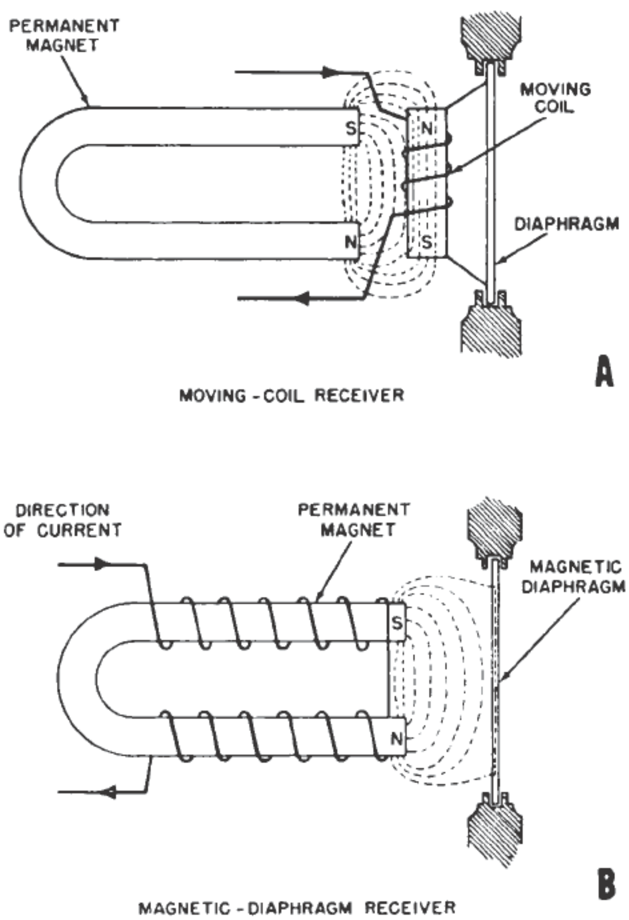


Figure 8-2.—Operating principle of telephone receivers: A, moving coil; B, magnetic diaphragm.

The magnetic diaphragm type operates by variation of the strength of the magnetic field. Variations in amplitude and frequency of the magnetic field cause corresponding variations of motion in the diaphragm. This is the most common type used in telephone systems.

Circuits

The electrical energy for a telephone circuit may come from a central source of power, or it may come from a local source, such as a dry cell, or a combination of dry cells.

When dry cells are used as the source of energy, the telephone installation is known as a local battery set. The cells provide the current for the talking circuit, but signaling is usually produced by a small hand generator.

When a common or central source of power is used to provide energy, the system is called a common battery system. The source provides the signaling current (as well as the current for the talking circuit) by means of a ringing machine attached to the power source.

The manual telephone installations at advanced bases may be the local battery type or the common battery system, or combination. Where local battery sets are used, telephones may be connected directly, although the connections are usually made through a switchboard.

Where a local battery system is established in the first days of occupation of an advanced base, it is possible to interconnect the switchboard of this emergency system with the switchboard of the common battery system, as soon as the latter has been established.

A simple diagram for interconnecting a local battery system with a common battery system is shown in figure 8-3.

The difference between a local battery and a common battery system is more than the difference in power source; the location of the power source also enters into the picture. A local battery system has a battery (either one dry cell or several) at each telephone station, but a common battery is centrally located, and serves all the stations of the system.

The common battery cannot serve all the stations unless the stations are in parallel with each other as far as direct current is concerned, and the battery is connected across the line instead of in series. The common battery, consequently, maintains a fairly constant voltage,

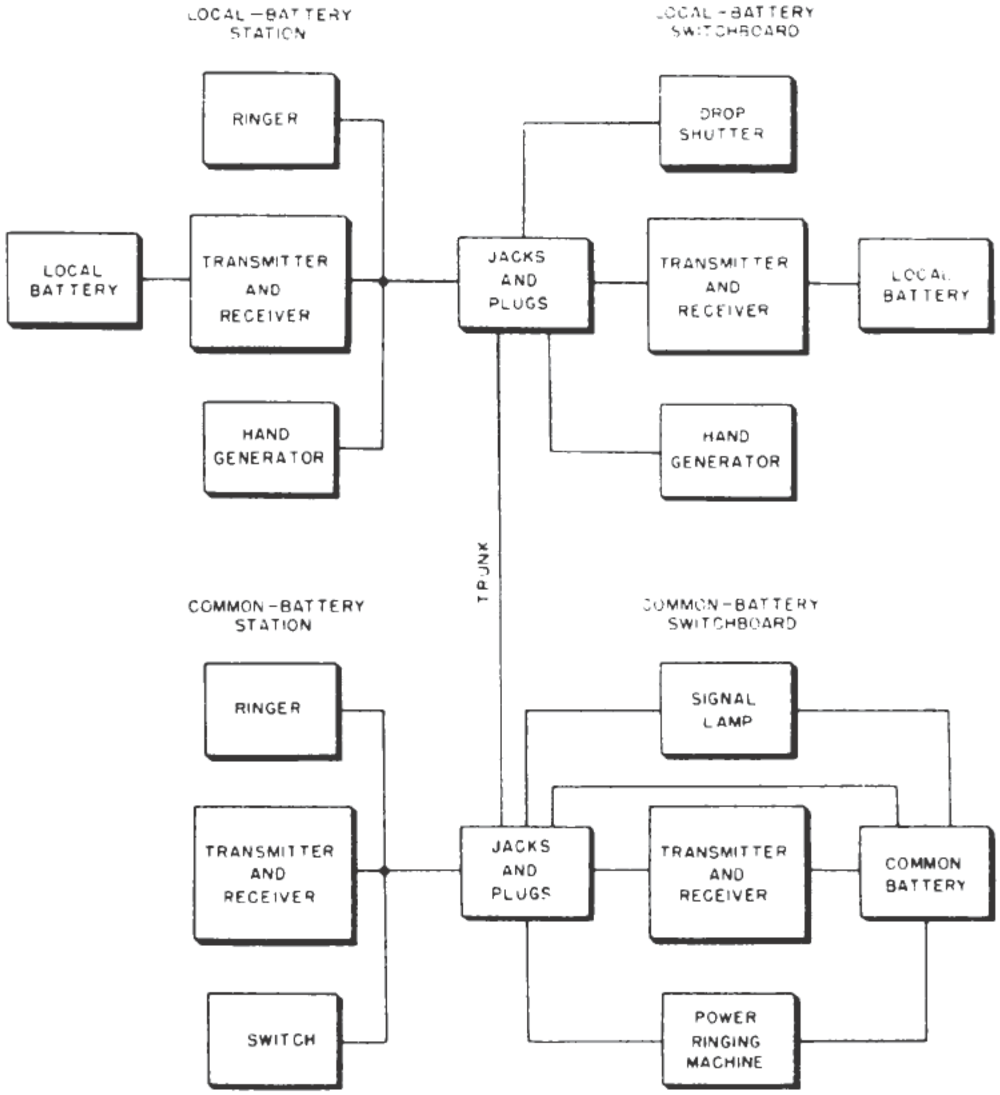


Figure 8-3.–Local battery system connected to a common battery system.

and gives a more uniform signal than the local battery. This signal is automatic when the receiver is lifted, so there is no necessity for having the hand generator.

Advantages of the common battery system, therefore, are that some of the equipment is simpler and cheaper; also inspection can be made at just one point, to see if the cell (or other power source) is operating. On the other hand, there is a disadvantage in that the common battery system requires much better line construction than is necessary for a local battery system. This is because any electrical unbalance in the wires impairs the quality of the service, and the distance of transmission. The switchboard equipment, too, must be more elaborate.

The hook-up of the components of a simple telephone system are illustrated in the four drawings shown in figure 8-4. In A, you see the schematic diagram; the negative terminal of the battery is connected to the ammeter; the ammeter is connected to the resistor; and the circuit is completed by a connection from the resistor to the positive terminal of the battery.

The most elementary form of telephone circuit is that obtained by connecting a transmitter

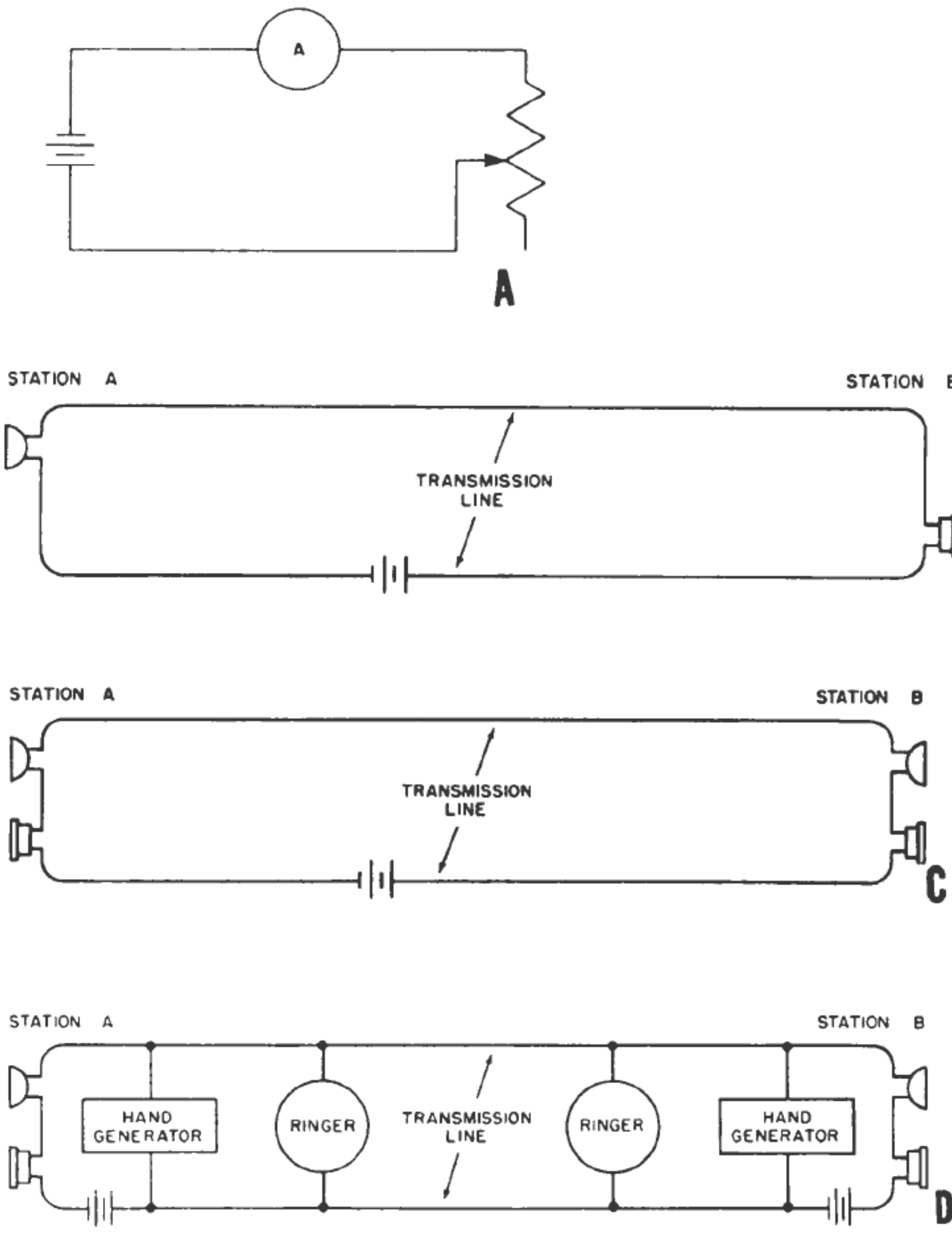


Figure 8-4.—Basic telephone circuits: A, schematic diagram; B, one-way conversation circuit; C, two-way conversation circuit; D, circuit providing for two-way conversations, and equipped with signaling device.

to a receiver as illustrated in figure 8-4B. This arrangement, however, permits of one-way conversations only, and is inadequate for most purposes.

The circuit shown in figure 8-4C permits two-way conversations, but lacks a signaling device to alert the station to which a message is to be relayed. The circuit in figure 8-4D, equipped as it is with hand generator and ringer, provides a signaling circuit and a two-way talking circuit.

The circuit shown at D of figure 8-4, using dry cells alone, will provide for voice transmission over short distances only, because of line resistance, which increases with line length. Both the range and the efficiency of the circuit

can be greatly improved by including an induction coil as part of the circuit.

The induction coil, as you have already learned, is a transformer device, consisting of a primary and a secondary coil, having no connection with each other. A transfer of energy takes place between the coils because of magnetic induction; that is, to put a varying current in one coil will induce an a-c voltage in the other coil. We know that the value of this induced voltage depends upon the ratio between the number of turns in the two coils, and upon the rate at which the current changes.

A circuit of two local battery stations, each with its induction coil, is shown in figure 8-5. Notice how, in each station, the primary coils are connected to the transmitter and to the battery. The secondary coil is connected to the receiver and to the line wires.

When you speak into the transmitter at set A, your voice causes a varying current to flow in the transmitter circuit. As this current passes through the primary coil, it produces an expanding and contracting magnetic field. This field cuts the turns of the secondary coil, and induces a current in the secondary circuit; the receiver at set B reconverts this current to sound waves.

The secondary coil of the induction coil usually has more turns than does the primary. Additional turns on the secondary coil give the same effect as a step-up transformer, and operate to cut down power losses.

Note that in the circuit illustrated in figure 8-5, there is a common connection between the primary and the secondary coils (a situation that does not exist in an ordinary transformer). This connection, however, does not affect the transformer action of the induction coils; it does serve the practical purpose of reducing the necessary number of handset cord conductors. This common connection can also be used for such special circuits as the anti-sidetone circuit, which reduces the passage of voice currents from transmitter to receiver IN THE SAME SET.

Hook Switch

In desk telephone subsets, a hook switch (see fig. 8-6) is used. The hook or cradle holds the receiver when the telephone is not in use. When the receiver is lifted, a hook spring forces two thin leaf springs together; small buttons on the ends of the springs make the contact. The opposite ends of the springs are connected to the circuit, one spring being connected to the transmitter circuit, and the other to the incoming line. In this way, both receiver and transmitter are put into action; breaking the contact between the leaf springs (by restoring the receiver to the hook) also breaks the talking circuit.

Magneto Generator

A small hand-operated generator is used in telephone circuits to provide a signaling service. The magnetic field is provided by permanent magnets—hence the generator is a magneto. It is cranked by hand, and at a normal cranking speed it will develop an emf of from 80 to 90 volts, at frequencies of 16 to 20 cycles. Increasing the speed of cranking will, of course, increase the generated voltage and the frequency.

A spring switch actuated by the shaft of the crank handle provides a make-and-break contact,

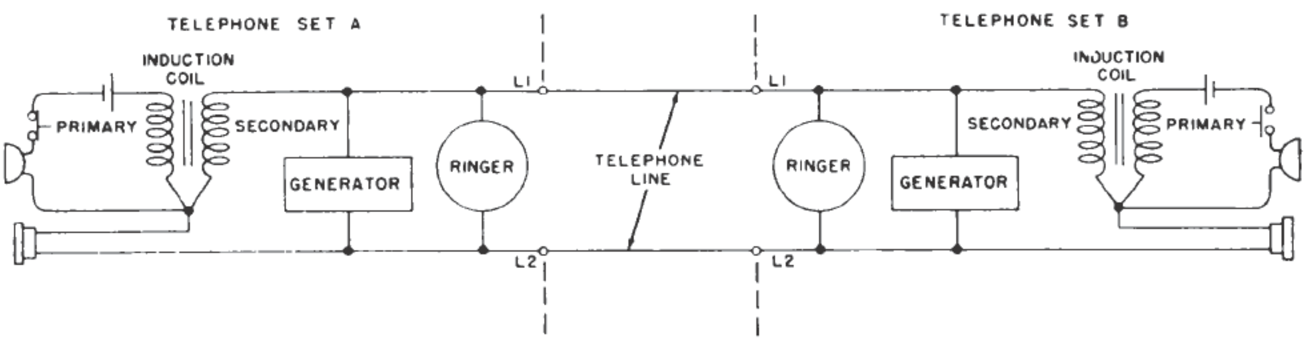


Figure 8-5.—Circuit between local battery stations, equipped with induction coils.

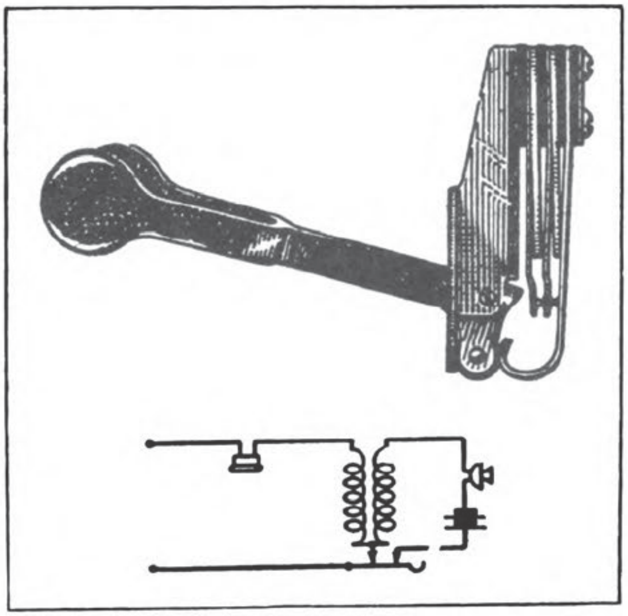


Figure 8-6.—Hook switch.

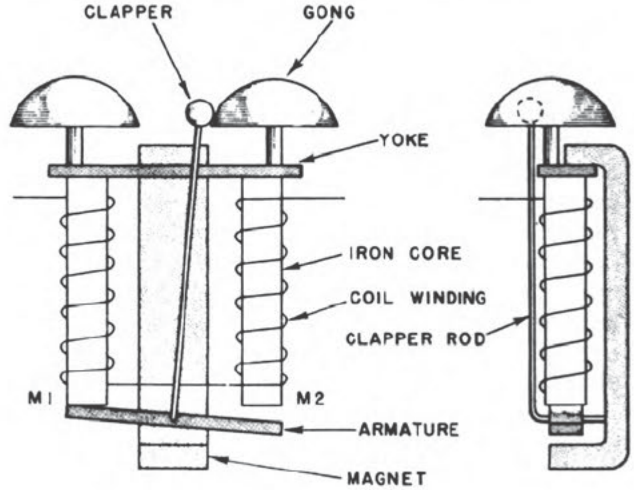


Figure 8-7.—Simplified diagram of a ringer.

in that it connects the generator onto the line, and removes the bell from across the line.

A recently designed hand generator is provided with a dial; you can either spin the dial, or crank in the usual fashion. The crank is pivoted, and fits into a compartment on the dial face when not in use. The generator unit can be removed from the equipment, and disassembled for servicing.

Ringer

The ringer is the signaling device of the telephone set. It is usually an electric bell operating on low frequency (20 cycles), and powered by the hand generator. You can understand the operating principle of a ringer by studying the diagram shown in figure 8-7.

Two electromagnets, formed of coils wound on soft iron cores, are permanently joined at the upper ends by a yoke of soft iron. An armature is placed under the cores of the electromagnets, and pivoted at the center. A U-shaped magnet is secured at one end to the yoke that joins the electromagnets; the opposite end of the U is bent around the armature, but does not actually touch it. The armature carries a clapper rod which can vibrate between two gongs mounted above the yoke.

When there is no current in the ringer, the magnetic lines of force are distributed evenly between the cores, and the armature is in balanced position. Alternating current through the ringer upsets this balance; since the current changes direction each half-cycle, first one core and then the other becomes magnetically stronger. The stronger magnetic flux in each core, alternately, attracts the armature; and as the armature is rapidly pulled first in one direction and then in the opposite direction, the clapper vibrates between the gongs.

LINE CONSTRUCTION

Advanced base telephone installations are basically the same equipment as is used at Army installations. For small installations, field wire is used as distribution cable; for large installations, field cable is used for this purpose.

Many of the problems that will arise in relation to the installing and maintaining of these telephone systems will be in connection with increasing talking range, with the overloading of lines, and with the interference that results when there is a transfer of electrical energy from one conductor to another. In order to understand these problems, you must have some knowledge of the principles of electrical theory as they apply to communications systems.

Electrical Theory as Applied to Transmission Lines

The electrical characteristics of transmission lines is an important factor in a telephone

system. These characteristics must be given some consideration in the operation of a system, since they involve (1) power losses along lines; and (2) the distortion and interference arising from interaction with adjacent lines.

At the same time, these characteristics and principles are complex and highly technical. Only the highlights of the subject will be given here.

Electrical Length of Transmission Lines

The electrical length of a transmission line is not a specific measurement, but is the relation between the length of the line and the wavelength of the transmitted signal. It is this fact that makes electrical length an important element in operating conditions.

A SHORT line is one in which the length of the line is considerably less than the wavelength of the transmitted signal. A LONG line is one in which the length of the line is equal to, or longer than, the wavelength of the transmitted signal.

But wavelength itself is also a relationship; it is the ratio between the velocity of the electrical wave and the frequency of the signal. It may be expressed by the following formula:

$$\text{Wavelength} = \frac{\text{Velocity}}{\text{Frequency}}$$

Attenuation

The name given to power losses along a transmission line, or in a network, is attenuation. In an open wire pair, attenuation depends upon the following factors: size, spacing, and material condition of the conductor; kind, number, and condition of insulators; and frequency of current. Under normal conditions, an open wire line suffers less attenuation than cable or field wires.

Loading

The talking range of cables and field wires used for military purposes are frequently increased by a method called LOADING. As applied to a transmission line, loading means increasing the series inductance of the line by adding external inductance. Loading improves line performance by reducing distortion and attenuation. This may be accomplished by lumped loading or continuous loading.

Lumped loading is the addition of loading coils with relatively high inductance at regular intervals along the line. This is the method that you will normally use for loading lines at advanced bases.

Continuous loading means wrapping the cable conductor with tape or wire of magnetic material. This wrapping distributes the inductance continuously along the line and results in improved performance. Continuous loading is used on submarine cables, since lumped loading would subject them to excessive strain at the points of insertion.

Interference

Interference is a serious problem on telephone lines. It may result from lightning or other natural disturbances of the atmosphere or from such sources as power lines, railway facilities, or other communication circuits. When two or more telephone talking circuits operate in parallel with each other, a transfer of electrical energy may take place and result in crosstalk. When telephone lines run parallel to power lines for a considerable distance, the transfer of electrical energy results in noise on the telephone lines. Battery chargers used to maintain storage batteries in a common battery system may cause a humming noise.

Interference may be kept to a minimum by maintenance of lines, transposing wires, balancing line capacities, use of repeating coils, and use of noise filters.

Good maintenance requires regular inspection of splices and joints, insulators, and other line equipment. Careful installation of lines also is important in helping prevent interference.

Transposition (or crossing over) of two lines is an effective method of reducing crosstalk which results from inductive coupling between the lines. Say two parallel telephone lines are running along together, one on the right and one on the left. When the telephone circuit on the left wire is in operation, a magnetic field is produced around the telephone wire. Because this field varies in intensity, a voltage is induced, and a current flows in the right wire. This current has the same frequency variations as the current in the

left wire, and consequently causes the conversation on the left wire to be heard on the right wire. This effect can be reduced or eliminated by transposing the left and right wires when they reach the crossarm. Thus, the original left wire becomes the right wire, and vice versa. At a distance specified by your crew chief, the lines will be returned to their original positions.

Capacitive coupling between adjacent telephone wires can also cause crosstalk. This effect can be reduced by transposing wires in the cable at points where one length of cable is spliced to an adjacent length of cable. Another method of reducing capacitive coupling is to connect the wires on one end of a short length of a twister pair to the cable pair, leaving the wires on the other end of the short length unconnected.

In emergency installations, 1-wire ground-return telephone circuits may be used in conjunction with a 2-wire circuit. A 1-wire circuit is especially sensitive to inductive interference from adjacent circuits; such interference can be greatly reduced by connecting the 1-line circuit to the 2-line circuit through a repeating coil.

Low-pass filters may be used to remove hum caused by battery chargers and similar equipment. These filters consist of a series of choke coils and shunt electrolytic condensers of rather large capacity. By filtering the output voltage, they remove the higher frequencies that lie in the voice frequency range.

Preliminary Planning

Transmission lines used in military telephone installations may be (1) field wires; (2) open wires; or (3) field cable.

Field wires consist of simple pairs of insulated wires twisted together. As a rule, you will use field wire chiefly for emergency and temporary installations; the transmission losses are so high that field wire lines must be held to minimum length.

Open wires are parallel bare conductors, strung on the crossarms of telephone poles.

Cables, as you know, consist of one or more pairs of wires, each wire individually insulated. Field cable is available in 5-pair and 10-pair cable, color coded, rubber insulated, copper jacketed, and equipped with a connector on each end.

Make a preliminary survey of the number of overhead and underground crossings that will probably be necessary; of the streams to be crossed; of the general type of terrain; and of possible obstacles to future maintenance of the lines.

In routing, consider points where the lines might be damaged by other construction, since everything at the base will probably be in a stage of construction at this time. When you have mapped the route along which the lines are to be laid, choose the wire or cable according to the type of line to be built.

Field Wires

In laying field wire, select the shortest and the most effective route. At advanced bases, savings of time and of material can be very important factors. Surface line construction is the quickest type, but is vulnerable to weather conditions and mechanical damage. If the wires are surface laid, they should be laid loosely, to minimize any damage from bombing.

Test the reels of wire for continuous circuit. Install test stations at exposed points on the wire line; for example, where circuits diverge (or may diverge with future expansion of the system), and at the end of a line that does not terminate in a switchboard. In the actual laying of a line, you will find additional points at which it will be desirable to set up test stations.

Use aerial lines near headquarters and camp areas, and at road points where it is likely that traffic will be diverted from the road.

Trees can be used as a support for aerial wires, but their sway during high winds may be greater than that of line poles. To offset this sway, a slightly more-than-normal sag should be provided. In some cases, you may have to use slings to give an intermediate support.

Where field wire is placed on poles carrying bare conductors, it must be placed below the lowest bare wire. Precautions should be taken to see that, in swinging or otherwise, it cannot come into contact with the bare wire.

At junctions between overhead and surface lines, tie the wires securely to the bottom of the support, and tag them. Where there are long stretches of overhead lines, install test stations at junctions with other types of construction.

Open Wire

For open wire installations, you will use steel wire, hard-drawn copper wire, or copper-galvanized steel wire, with diameters between 80 and 165 mils. Two wires constitute a line.

The conductors are strung on electrical insulators mounted on the crossarms of telephone poles. Since each basic telephone circuit requires two wires, you will have to mount quite a number of bare conductors on crossarms. Keep each conductor in place by tying it to an insulator. Space the wires a standard distance apart—8 inches for a single pair of wires, 10 to 12 inches when more than one pair of wires are strung.

The operation of stringing telephone wire is very similar to the operation of stringing power line wire. You should now be familiar with the main operations; that is, reeling out the wires, raising the wires to the crossarms, tensioning the wires, and tying the wires in. If you are uncertain of how to go about these operations, reread chapter 6 of this training course.

Telephone Cable

Because of the great number of wires that are carried in a cable of nominal cross section (for example, 1 1/2 inches in diameter), there are certain disadvantages in its use. The voltages carried are low, which means that a single wrap of dry paper is enough insulation for each wire; but a very small amount of moisture entering the cable can produce a short. This is because the insulation is so thin, and the wires so closely packed together.

Types

Types of telephone cable, according to the purposes served, may be defined as follows:

1. Exchange: outside cable of a central office that furnishes the facilities for sending out and receiving calls through local switchboards.
2. Toll: quadded or nonquadded conductors, or a combination of the two, providing for communications between two widely separated local exchanges. (A quadded conductor is one in which all or some of the conductors are arranged in quads or groups of two pairs.)
3. Trunk, or tie: cable used primarily for connecting two narrowly separated telephone exchanges.
4. Other: post or administrative cable refers to cable forming part of a fire-control communications system. Target range cable refers to cable that is used exclusively in the operation of a target range, and has no connection with other communications systems. Fire alarm cable refers to cable used exclusively in connection with a fire alarm system.

Where open wire requires only a support point at each pole, telephone cable requires a support along its entire length. So before you can string the cable, you must first provide a galvanized steel wire (messenger) along the cable right-of-way.

Suspension Clamp

The first step in stringing the messenger is to provide support at each pole, by installing a suspension clamp. This consists of two long metal bars that can be clamped together by tightening a nut and bolt assembly. An overhanging lip on one of the bars forms a groove that holds the messenger.

Suspension Strand

When suspension clamps have been mounted on all the necessary poles, you can string the messenger, or suspension strand. As the strand is unreeled, it is carried up each pole, and placed in the suspension-clamp groove. The clamp nuts must be tightened just enough to keep the strand from falling out.

The next step is to pull the suspension strand to the proper tension, or sag. Bringing the pulling line through a snatch block set at the top of the pole will prevent the suspension strand from being pulled out of the grooves on the clamp.

After the suspension strand has been pulled to the specified sag, it must be dead-ended. You can terminate the strand at the eye bolt used for the guy wire. Thread the free end of the strand through a thimble in the eye bolt, then double it back and clamp it to the main part of the strand.

The last step in the installation of a suspension strand is the tightening of the suspension clamps. At first you tightened them just

enough to hold the strand in the groove; now they must be fully tightened. The best procedure is to start at the middle pole, and work toward each end in turn.

Cable Rings

One method of fastening the cable to the supporting suspension strand is to use cable rings. To get these rings on the messenger, you will very likely have to use a cable car, such as the one illustrated in figure 8-8.

A loop of wire attached to the cable car holds the cable rings; a drag line, also attached, is threaded through the rings. Markings on the drag line assist in spacing the rings. The drag line provides a pulling-in line, when you are ready to pull the telephone cable through the cable rings. If you are careful to line up the reel with the messenger, you should be able to pull the cable through smoothly.

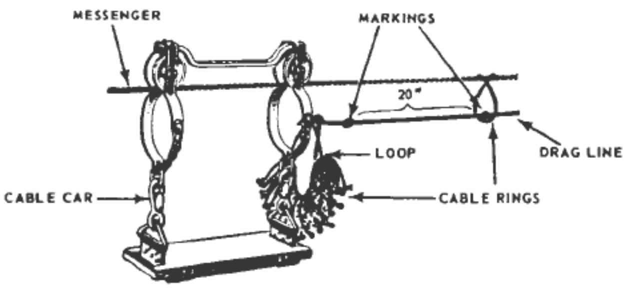


Figure 8-8.—Cable car for placing rings.

Lashing

Another method of fastening the cable to the suspension strand is by lashing. The cable must be brought up to the strand; then the two are lashed tightly together with a spirally wound wire.

To bring the cable up to the strand, you can use temporary cable rings, which can be removed as soon as the lashing is applied. An alternate method is to mount the cable reel on a truck, and pay the cable up to the suspension strand through a cable guide attached to the lashing machine.

Underground Cable

Direct burial of cable, which is a method frequently used in laying field cable, has a great advantage in that an underground system is usually easier to construct than is an overhead system. Disadvantages arise, however, when it becomes necessary to locate cable faults. In addition, cable that is in direct contact with earth is likely to become corroded or damaged by contact with rock surfaces.

Protection against corrosion or damage will be supplied by placing the cable in ducts; this method also provides for pulling in and replacing the cable when necessary. Manholes and splicing chambers built at intervals along the line will serve as convenient points where the cable can be installed in ducts.

In laying underground cable that will be buried in the earth, you can use a plow to form the trench. By mounting the reels on the plow, you can dig the trench and lay the wire at the same time. Make the trench no wider than necessary, but from 6 to 18 inches deep; remove any rocks that might damage the cable. Where a reel runs out, bring the end of the wire into a splicing chamber, or up to the ground surface, in order to splice it. Replace excavated dirt with a scraper, a bulldozer, or a caterpillar tractor.

In digging the trenches for the conduits or ducts, have the trenches slope toward the manholes. A slight slope will provide a drainage system for any water that might seep into the trenches.

Make sure that the ducts have been cleaned of dirt or cement before the cable is pulled through. Push a rodding tool through from one manhole to the next. Attach a rope to the threading wire which you have previously fastened to the last section of rod in the rodding tool. When the rope appears in the manhole, fasten the end to the pulling source. The other end should be connected to the cable by means of a cable grip.

Splicing in Cable Terminals

The procedures to follow in splicing telephone cable are described in the following chapter. At this point, it is enough to warn you that you must break into the lead sheath in order to splice. This sheath provides the moisture-proof seal; ensure that this seal is as secure when you have finished splicing as it was originally.

Outside Terminals

In carrying telephone wires from switchboard to subsets, there will be numerous points at which the cable will have to be spliced. Terminal boxes are mounted at convenient points along the pole lines—two or more boxes must be used, if the number of telephones to be installed exceeds the number of terminals in one box.

The required wires are brought out from the cable and connected into these boxes. Outside drop wires are then installed to lead from the terminal boxes to the subsets.

Mounting Boxes

Mounting the boxes on the poles is a job that is usually given to new men in the CE service ratings. Attach the plate or bracket to the pole, at a point below the main cable, and secure it with four drive screws. Then place the terminal box in the supporting notches in the bracket.

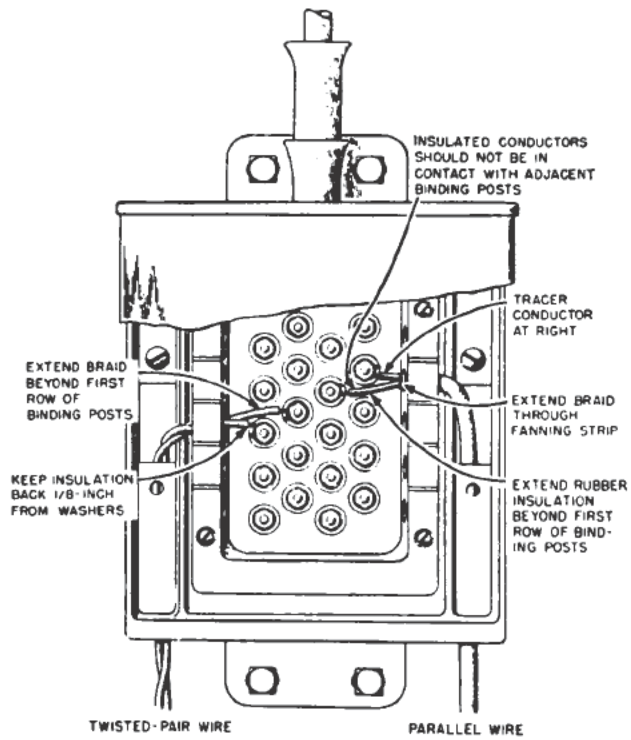


Figure 8-9.—Connections at the terminal box.

Panel

Within the box is a panel fitted with binding posts, nuts, and washers. A short length of lead-sheathed cable is attached at the back of the box. Drop wires from the individual subsets must be attached to the binding posts; the wires are then drawn out from the cable stub, and attached to the binding posts. If you study figure 8-9, you will see how these connections are made at the panel of a terminal box.

As soon as the wires in the cable stub are spliced to the designated wires in the main run, you will have a completed circuit from main line to subset. In figure 8-10, there is an example of how a terminal box looks when it has been installed on a pole; the cable stub is coiled and ready for splicing to the main line. Tapping the main line is normally the last step in the installing of a telephone.

SWITCHBOARDS

A single receiver and transmitter provides only for one-way communication. Adding a second transmitter and a second receiver provides two -way communication. Extending the number of telephone stations, however, can result in a maze of wires; for example, with six transmitters and six receivers, there would have to be five wires from each transmitter—one to each of the three receivers, and two more wires to connect the specific transmitter to the other two.

An important saving in the amount of line wire required, and a simplification of the wiring arrangement, result from the use of a switchboard. Figure 8-11 shows an arrangement whereby eight telephone stations are interconnected through a switchboard. As you can see, each station is connected DIRECTLY to the board, and all necessary interconnections of transmission lines are made at the switchboard through cords fitted with plugs.

Types

Most switchboards used at advanced bases are the types in use by the Army Signal Corps. Two common types are the SB-22/PT (a 12-line switchboard) and the TC-2 (a 57-line central office set). The type of switchboard used will depend upon the size of the Navy activity,

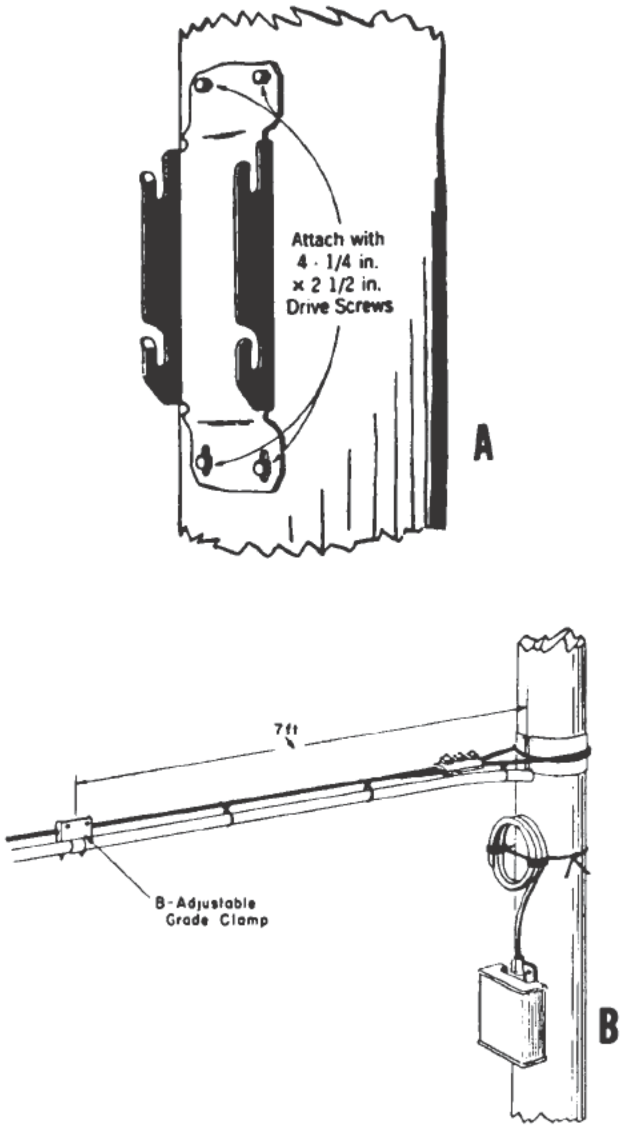


Figure 8-10.—Pole-mounted terminal box: A, mounting plate; B, box installed.

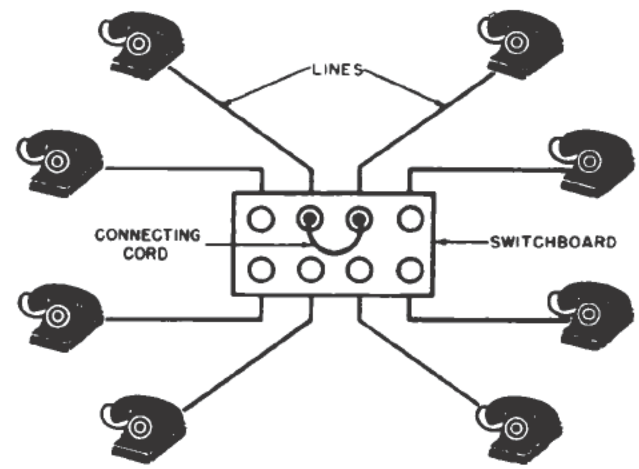


Figure 8-11.—Block diagram, showing eight telephone stations connected to a switchboard.

the speed with which telephone service must be installed, and the expected time the installation will exist.

In a later section of this chapter, you will find a discussion of field-type telephone equipment, including the two switchboards just mentioned.

Line Capacity

The capacity of a switchboard is determined by the number of line packs that it can accommodate. There is a wide variation in the number of battery line circuits and trunk circuits that may be provided, as you will see when you read the section, Field Sets, later in this chapter.

Each line pack consists of a reel unit, a drop, a jack, and an identification strip. The cord of the reel unit is flexible; one end of the cord is attached to the reel, the other is equipped with a standard plug. Since the reel is spring loaded, the cord automatically retracts when there is no pull on it.

There is also an operator's pack with a reel unit identical to that of the line pack, with some type of signaling equipment, and with a switch for making the necessary corrections.

Distribution Frames

When a large number of lines come into a switchboard, there must be some method whereby they can be quickly connected to the proper jacks in the board. This is accomplished by using distribution frames. Not only do these frames provide for an orderly arrangement of incoming lines, but they also are an effective means of identifying outside lines where they enter the central office.

Main distribution frames (MDF), whether in manual or in dial systems, serve these two purposes: connecting the inside equipment with outside lines, and interconnecting the various units of inside equipment.

Each outside line is connected to a PAIR of terminals on one side of the frame, as

indicated in figure 8-12. Notice how the corresponding terminals on the opposite side of the frame are connected to lines to the switchboard. For each line in use (that is, connected up in this fashion), jumpers or cross-connecting wires make a connection between terminals.

The side of the frame carrying the terminals to which outside wires are connected is usually known as the vertical side of the MDF; cables or lines from the inside equipment terminate on what is usually called the horizontal side (though in some installations, both sides are vertical). Cross connections between vertical and horizontal sides are made by jumpers.

Use of distribution frames permits a rapid switching of the switchboard load. It also makes outside wires accessible without any disturbance of the switchboard wiring, and provides a convenient place from which to test for line faults.

Distribution frames may be either the wall frame or the floor frame type. Wall frames are used in small central offices, and are built up of units that can accommodate 20 pairs, or lines. Screw type terminals are frequently used, since they allow for easy disconnections. Jumpers are flexible and can be made fast to any set of terminals. Standard floor frames, also used at military installations, differ from wall frames in having one side vertical, one side horizontal. (Wall frames have two vertical sides.)

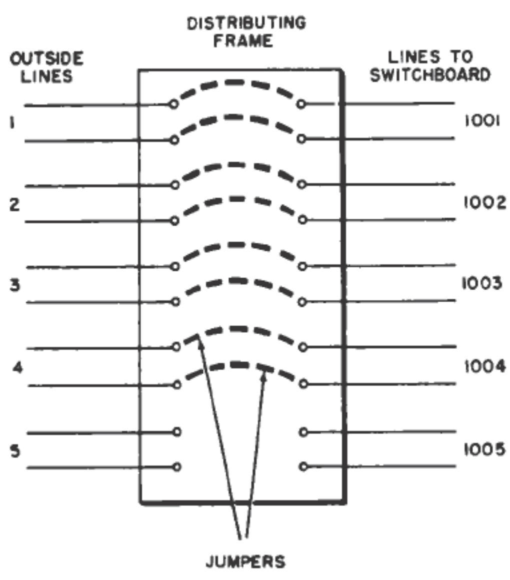


Figure 8-12.—Connections made through the distribution frame.

Another distinction that you may find made between distribution frames, in addition to their identification as wall or floor frames, is to label them as Type A and Type B. Where the vertical side of a frame is connected to the switchboard, the frame is called a Type A frame; where the vertical side is connected to outside lines, the frame is Type B.

Switchboard Protective Devices

Because the distribution frame is the dividing point between the outside plant and the inside plant, it becomes the logical location for central office protective devices.

The switchboard must be protected against excessive voltage, including such natural hazards as lightning; and against excessive current, including current surges through unexpected channels. The protective devices must operate BEFORE damage occurs, but must not be so sensitive that they will interrupt service because of lesser types of artificial or natural hazards.

Air gap arresters (or open space cutouts) provide protection against excessive voltage. Protection against accidental current surges is needed only if such excessive currents flow for an appreciable length of time; a heat coil is the best device for taking care of these hazards.

Fuses protect against excessive current other than instantaneous surges. In a large central office, there may be hundreds of switchboard fuses, to protect the switchboard from its own battery current. If a fuse is not available when you need a replacement, you can use a piece of fuse wire of the proper rating. Observe these two precautions in making a replacement: never use copper wire, and never replace a blown fuse by one of larger capacity than the circuit requires.

Circuits

On a common battery switchboard, there will be a number of circuits, notably the telephone relay circuit, common battery line circuits, common battery cord circuits, and the operator's telephone circuit.

The relay is a control device that provides for automatic signaling on the common battery systems. In effect, a relay is an electrically operated switch, which makes it possible to

control (by means of one switchboard circuit) the operation of one or several circuits on other switchboards. There are many different types of relays, as far as construction goes, but the principle of operation is the same for all.

Essential parts of the relay are armature, windings, core, and springs. It is the motion of the armature that opens or closes the controlled circuit. Windings provide the path for current flow; the number and types of winding depend upon the particular function of the relay. The core is the magnetic material. The contact springs are of silver or silver alloy, and either open or close normally. The number and arrangement of contact springs depend upon the strength of the magnetic field, which in turn depends upon the number of turns and the value of current in the windings.

Relays are provided with covers, to keep out dirt and to protect against mechanical injury. Some have a small setscrew, called a residual screw, which can be adjusted to overcome residual magnetism in the armature.

Common battery line circuits are of three types:

1. Series lamp line circuit, with a lamp connected through the auxiliary contacts of a cutoff jack

2. Series relay line circuit, in which a relay is included, in addition to a lamp and cutoff jacks

3. Cutoff relay line circuit, in which a cutoff relay is substituted for the auxiliary contacts of a cutoff jack

The function of cord circuits is to prevent the branch containing the common battery from shorting out the receiver of the listening station. A retardation-coil cord circuit uses a relay to provide automatic supervisory signals; a repeating-coil cord circuit uses separate relays (supervisory relays) for this purpose.

A third type of cord circuit, known as a universal cord circuit, is often used on military switchboards that serve both common battery and local battery stations. Such a circuit is illustrated in figure 8-13. It supplies battery voltage to the common battery lines, but not to the local battery lines.

This circuit is called universal because it provides a talking circuit, in either direction between two common battery lines, or between two local battery lines, or between one common battery line and one local battery line.

The various cord circuits provide for ELECTRICAL paths between selected stations, but they are not sufficient of themselves to enable the user of a calling telephone to tell

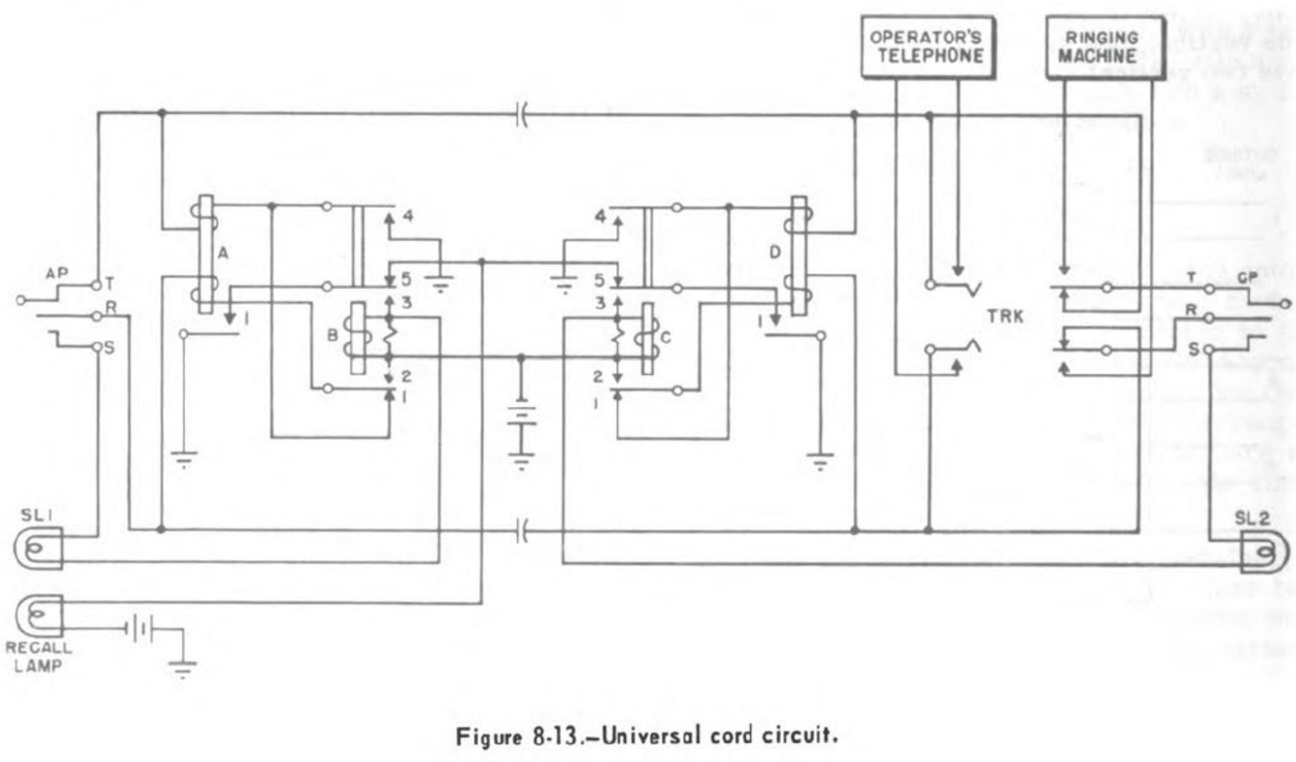


Figure 8-13.—Universal cord circuit.

the switchboard operator what station he wishes to call.

For this, it is necessary that the operator be able to listen or to talk into each telephone; and this need is met by installing an operator's telephone circuit for the entire switchboard. The function of this circuit is to connect the operator's telephone set across the line from any calling station, either before or after the called station is connected. The operator's telephone circuit, therefore, provides an additional voice frequency path which is in parallel with the cord circuit.

Generally, the operator's set is connected to the switchboard by means of a plug and jack. A lever switch allows the operator to cut his telephone into or out of any cord circuit. It differs from user's set in having no ringer and no hook switch contacts. Switchboard lamp signals perform the function of the ringer; operator's jack, plug, and lever switch substitute for the hook switch.

Ringing Machine

The ringing device may be powered from an automatic power source (such as a distribution line) that takes the place of a hand generator. The voltage of the standard power source may be either a-c or d-c, but this device converts voltage to a-c, and to required frequency. The operating principle is that of a vibrating reed, either converter or interrupter.

If power is from a battery, the d-c vibrating reed converter changes this d-c voltage to an a-c voltage of 20 cycles per second (cps). If the power input is a-c 110-volt 60 cps, the a-c vibrating reed interrupter is adjusted so that it closes the output circuit for one-half cycle, and opens it for 2 half-cycles (that is, a complete cycle).

When the output circuit is open, the voltage falls to zero; when the circuit is closed again, the voltage is of opposite polarity. Thus the actual output voltage consists of 2 half-cycles, one positive and one negative, separated by an interval of zero voltage. In this way, the 60-cycle input voltage is reduced to 20 cycles.

Switch Key

The switch key on the switchboard is simply a make-and-break spring switch. When you move the key handle, you cause a cam to press against the spring of the switch, to open or to close the contacts in the cord circuit.

When the switchboard operator receives an incoming call, he pulls the key forward into the talking position. When he has made the connection with the circuit on which the call is to be placed, he pushes the key back, into the ringing position. When the calling party has a connection with the party called, the operator lets the key return to neutral position. There is now a closed circuit from calling to answering plug; this circuit is broken when one of the telephones is returned to its cradle.

INSTALLING THE TELEPHONE

After you have erected the outside lines, installed the switchboard, and provided for the necessary connections between main lines and subsets, a few simple steps will be enough to put the telephone system into operation. It might be wise, at this point, to enumerate the steps, and then to discuss them at greater length in the succeeding sections.

Span the drop wire from the pole to the building, and train it along the building to the entrance hole; bring it through the hole, and connect it to the INPUT end of the fuse, lightning arrester, or other protective device.

Connect the inside wiring to the OUTPUT of the protector; run the inside wiring to the location of the subset; terminate the inside wiring at the connecting block.

Attach the subset wires to the connecting block; secure the drop wire to the pole; tap it to the designated pair of wires in the main run (through the terminal box if cable is used, directly to a pair of open wires if the main run is strung on crossarms); check the installation.

Wiring

The drop wire is exposed to the weather, and both wind and rain can do damage unless the wire has been given proper protection. Both conductors should be insulated with a rubber compound, and then the wire should be further protected with a covering of weatherproof cotton braid. The wire used inside a building is rubber insulated, but protective braid covering is not necessary, except in very damp locations.

Drop wire may be either the twisted pair type or the parallel drop type. The twisted pair consists of two conductors separately covered, and then spiraled together. In a parallel drop wire, there are two wires, separately insulated, that run parallel to each other, under a single braid covering.

The drop wire must have a definite sag between pole and building, yet at the same time the weight of the wire should not produce a strain on the remainder of the run. CLAMPING the drop wire will prevent such a strain. The clamp installation consists of a wedge secured to a copper wire loop, and a tapering sleeve.

The copper wire loop is attached to the support point on the pole. Then the sleeve is placed over the drop wire, with the tapered end toward the support point, and pushed firmly up on the wedge. When the free end of the drop wire is attached to the building, the weight of the span produces a tight fit at the wedge.

The type of support that you will use in training the drop wire along the building will depend upon the composition of the building wall. On wood or other combustible material, these supports must be insulated. Anchor bolts will have to be used on brick walls; toggle bolts, on hollow tile. Figure 8-14 indicates some of the types of wire supports that you may use in securing wiring to the outer walls of various buildings.

It is possible to run wire on a quonset hut without drilling into the sheet metal. The wire can be secured with nail knobs, driven in at points where the sheet metal is secured to the ribs of the structure. On a metal building of this type, you must use insulated knobs.

For a frame building, attach the drop wire with an S-knob and a drop wire clamp. In a line with the S-knob, and about 6 inches away, screw in a C-knob; still moving along a horizontal line, a few feet farther along the building, attach an insulated screw eye. The actual distance will depend upon the location of the entrance hole, since you will want to train the wire to a point almost above it. Another screw eye is needed, below the first, and directly above the entrance hole; and another C-knob should be installed about 2 inches above the entrance hole. Figure 8-15 illustrates this drop wire installation.

Run the drop wire over the S-knob, securing it with tie wire; carry it through the groove of the C-knob, and tighten the knob; bring it through the insulated screw and down to the lower C-knob; carry it through the groove, and tighten the knob; and then through the entrance hole. A porcelain tube may be inserted, as a protection for the entering wire.

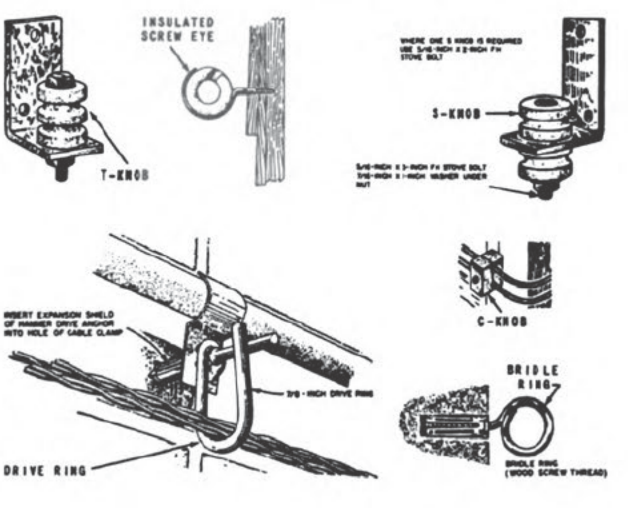


Figure 8-14.—Supports for wiring.

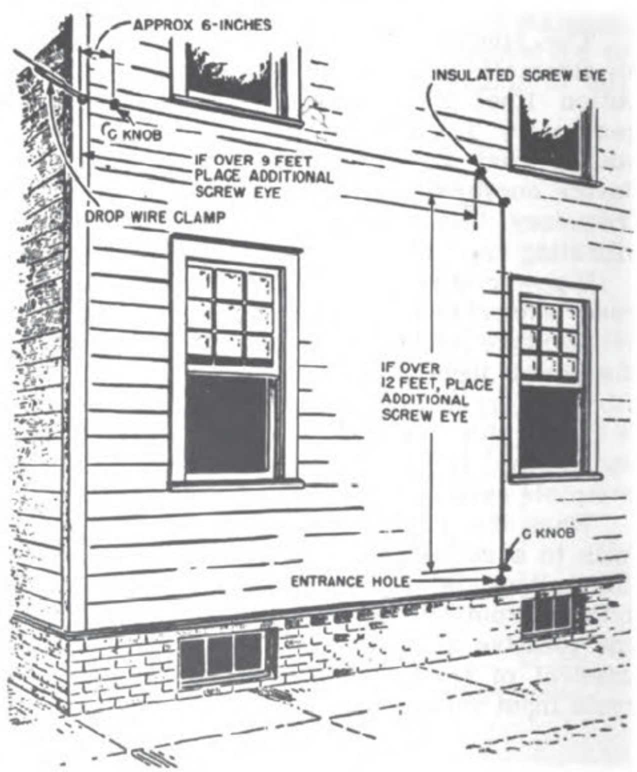


Figure 8-15.—Drop wire installation on a frame building.

Connections to Protectors

The wire from pole to building is exposed to hazards from lightning discharges and crosses with light and power lines; therefore, it requires some protective device, such as a fuse or lightning arrester. This protector may be mounted outside, enclosed in a weatherproof metal can, or it may be an inside unit, mounted on a porcelain block.

Fuses are inserted in series with the line, but arresters are placed between line and ground. Thus, current must pass through the fuses before it can reach the output terminals (to which the subsets are connected). The lightning arresters ensure that high potential is bypassed to ground before it can reach the output terminals.

When you bring in the drop wire, remove the insulation for about 3/8 inch from the end, and then bring the bare ends of the conductors around the input terminal posts on the protector. Give each wire a 3/4 clockwise turn around its post, and then tighten the terminal nuts.

Connect the inside wiring to the output terminals; that is, to the outside binding posts on the bottom of the protector.

The center terminal is the ground terminal for the arrester. Connect it, by a single insulated conductor, to a cold water pipe, if possible. If there is no available metallic object in close contact with the ground, drive a ground rod. NEVER ground to gas pipe systems, nor to lightning rods. Hot-water, steam, or sprinkler piping provide poor grounding, and electrical railways should never be used for grounding any electrical equipment except that supplied from the railway circuit itself.

Connections to Subsets

In routing the inside wiring from protectors to subset locations, keep the run parallel with or at right angles to the building walls. Wherever wires must pass around sharp corners, or over metal objects, use friction tape to protect them from mechanical injury. If you must run wiring along a floor or ceiling, protect it with a metal raceway. You can secure wiring to walls and ceilings with insulated staplings, since this inside wiring carries a protected low voltage.

At the telephone location, run the inside wire on the connecting block. This block will probably be in the form of four terminal posts mounted on a composition base, and provided with a removable metal cover.

Bring the inside wire to the back of the connecting block, wind it around the projecting lugs, and connect it to the terminal posts on the face of the block. There will be less strain on the wire than if the connection were made directly, and there will also be enough wire so that it can be reconnected if a bare end breaks off.

These connecting blocks provide not only a point at which to connect inside wire and telephone cord, but also a convenient test point.

Connections to the Main Run

Before you can make final connections with the main run, there is the matter of TRAINING the drop wire back to the connecting point in the run. The method to follow in doing this will depend upon whether the drop wire is to be connected to open wires, or to a terminal box.

If the drop wire is to be connected to OPEN WIRES, train it under the crossarm, to the point of connection. Use bridle rings to support the drop wire along the crossarm. The type of bridle ring you will use has an open spiral eye through which you can slip the wire after the ring has been screwed into the crossarm.

Each conductor of the drop wire should be separate, as if for splicing. You can then wrap each of the two conductors around the main run wires, for about three turns, before extending the conductors to the point of connection. The crew chief will have to tell you which pair of wires to use in the main run.

The joint at the connection is solderless. The connector will probably have a slotted bolt, nut, and washer assembly. Place the main wire in the slot, and wind the bared conductor of the drop wire around the bolt, between two washers; be sure to wind in the same direction as the nut tightens. Turning down the nut will ensure a firm joint.

Making a drop wire to a TERMINAL BOX is a simple operation, already discussed in the section on Outside Terminals. The important things to remember are: connect the pairs of binding posts to the proper wires in the main cable; remove only a small amount of insulation from the drop wire, so that there will be no risk of a bare conductor touching an adjacent post; make one conductor of the drop wire

slightly shorter than the other, to accommodate the post positions; and make sure that the conductors are wound around the posts in the same direction as that in which the nuts tighten. A careful study of figures 8-10 and 8-16 will give you a clear idea of how to connect the drop wire to the terminal box.

At the pole, you will have to attach the tracer conductor of the drop wire to the ring line, and the plain conductor to the tip line. The tracer conductor must always be connected to the RIGHT HAND binding post, to ensure that the connections are made correctly. This is also standard procedure in making connections at the protectors and at the connecting blocks; that is, always connect the tracer wire to the right hand terminals.

At the central office, the positive side of the battery is permanently grounded. This makes the negative or tracer wire a hot wire, and therefore it must be readily identifiable at all points, for purposes of testing and repair. In a twisted-pair drop wire, the outer covering often has a raised thread to identify the tracer wire. In parallel drop wire, the conductor with the ridged insulation is the tracer wire. In the inside wiring, the wire with a red thread is the tracer.

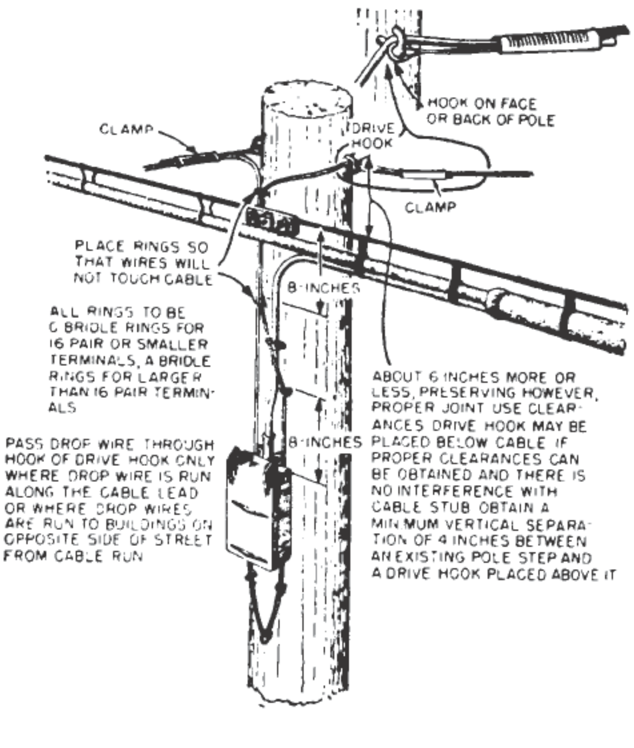


Figure 8-16.–Drop wire runs from a terminal box.

Hooking Up the Handset

Telephone sets are practically self-contained units. In a desk or table set, the base contains ringer, induction coil, condensers, and hook switch; the transmitter and receiver are contained in the handset. Once the terminal lugs of the telephone cord are connected to the block, the set is installed.

A hanging desk set has three units: bell box, handset mounting, and handset. Like the table set, the handset includes transmitter and receiver; the bell box contains the ringer, induction coil, and condensers; but the hook switch is in the handset mounting.

Checking the Installation

As soon as the telephone is hooked up, check to see if the connection has been made to the proper line. Then have someone ring back from the switchboard, to check the bell circuit. Observe the strength and the quality of voice transmission, to see if it is satisfactory.

Bells and Buzzers

Where there are several telephones at a station, all working from one or two incoming lines, bells and buzzers will be a great convenience. To energize a bell circuit, you will need a low voltage source, either dry cells or a bell transformer connected to a lighting circuit. You will require a push button to make or break the bell circuit, a signaling device, and a wire to connect these components.

Mount a bell at each telephone. There should be a push button for each bell, but these buttons should be located together, at the central telephone location. Connect the transformer to the lighting circuit at any convenient point.

Use No. 18 wire for the bell circuit. This wire is attached to the secondary side of the transformer; one conductor is trained directly over to the bell, the other connects with the pushbutton. Another wire runs from bell to push button, being connected at the screw terminals of each of these components. Use No. 14 wire to connect the primary side of the transformer to the lighting circuit, and the signaling circuit is completed.

FIELD SETS

Not all telephone systems will have to be installed in their entirety. The Navy has some functional components that provide for speedy installations at advanced bases. These components include central office sets, distribution systems, and station equipment, capable of serving small, medium, or large bases.

Since the Seabees use considerable Army equipment, it will be helpful for you to have a brief description of some of the Army field sets that you may need to operate. Some common types are the following sets: the TC-2 set, a 57-line switchboard; the TC-10 set, 1 to 6 switchboards of 90-line capacity; the SB-22/PT 12-line switchboard; and the TA-312/PT telephone set.

TC-2 Set

The TC-2 set is a central office set with the receivers mounted in the headband. It consists of a combination of local and common batteries, switchboard, MDF, power unit, power panel, rectifier, and accessories. The switchboard has 57 circuit lines and three trunklines for connections to other switchboards.

The power unit is a self-contained 2500-watt a-c generating set, driven by a gasoline engine, and producing a 120-volt single-phase 60-cycle current. The panel contains a voltmeter and ammeter, for use in controlling the rate of charge of the storage batteries. The rectifier is capable of charging the storage batteries at a maximum rate of 12 to 14 amperes.

The components of this set can easily be damaged, so use proper care in unpacking the assembly. Locate the switchboard as far as possible from any source of excessive noise.

Figure 8-17 illustrates the cording diagram of a TC-2 set. Cording is a term used in connection with telephone switchboards. A cord may be a small, flexible, insulated cable, or a stranded wire.

TC-10 Set

The TC-10 is also a central office set, especially useful for a headquarters installation. It is powered by storage batteries, composed of 24 cells and having an output of 48 volts. It can operate on a 110- to 120-volt 60-cycle current, if the latter is available. It has a full-wave rectifier for charging the batteries, and a control panel.

This set has a capacity of from 1 to 6 switchboards. Each switchboard contains 30 local battery line circuits, 60 common battery line circuits, 4 universal trunk circuits, 15 universal cord circuits, and 1 conference circuit with 10 jacks.

In addition, there is a main operator's telephone circuit, an auxiliary operator's telephone circuit, a power and heating circuit, and an emergency ringing circuit. The auxiliary operator's telephone circuit allows a second operator to handle calls during traffic loads. One distribution frame is furnished with each switchboard.

Unpack this assembly with care, and save the case so that it will be available for use if the set is later to be transported to another location.

Figure 8-18 shows the cording diagram of this set.

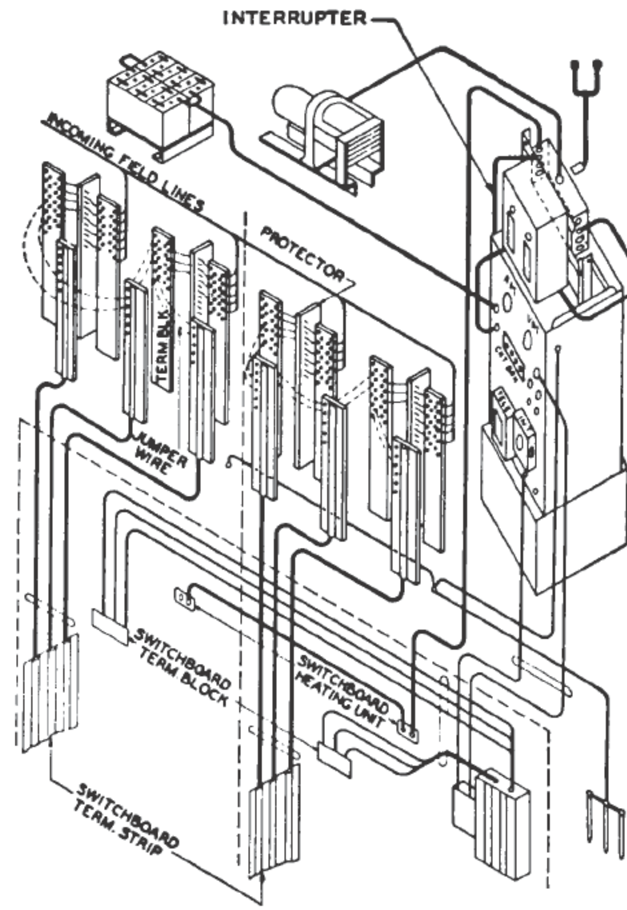


Figure 8-17.—Cording diagram of a TC-2 central office set.

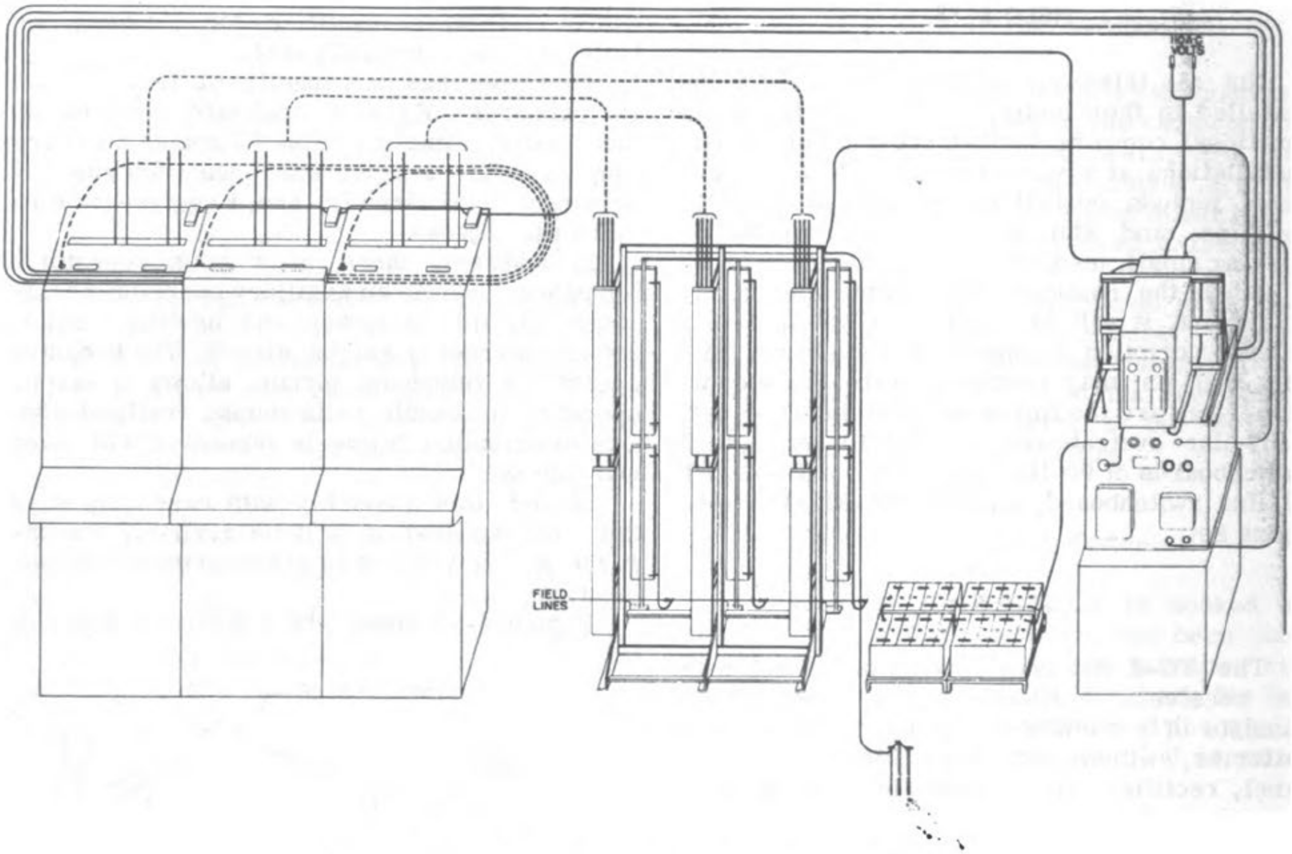


Figure 8-18.–Cording diagram of a TC-10 central office set.

SB-22/PT Switchboard

The SB-22/PT switchboard is very useful for 12-line circuits, or a combination of two such circuits. This set is immersion-proof, portable, operates on local batteries, and requires no special mounting equipment. It may be used for connecting local battery lines with teletypewriters and remote radio control radio communication. The SB-22/PT set is very useful for establishing a working telephone system.

In addition to the battery case, handset-headset, and switchboard assembly, there is also an accessory kit. The switchboard assembly is a metal case containing 36 binding posts, 12-line jack telephone circuits (line packs), and one operator telephone circuit (operator's pack). The cord of the reel unit on each line pack can be extended up to a distance of 35 inches.

The case has openings on either side, to allow for entrance of the wire; and a writing surface on the rear door allows for identification of the binding posts. The set is powered by four dry-cell batteries.

When the crank of the hand generator serving a telephone is turned, the ringing current operates the line drop; the fall of the drop tells the operator which station is calling and also completes a circuit in the operator's pack. Completing this circuit causes a buzzer to sound or a lamp to light, thus providing a more positive signal than that given by the line drop.

The jack in each line pack is used to interconnect the telephone circuits. As you can see from figure 8-19, each circuit has its own jack.

The operator's handset-headset unit is a bayonet-locking 10-conductor receptacle used with the plug on the handset-headset cord.

The identification strip is a piece of white plastic, fastened to the front of the line jack. Marks on this strip identify the telephone circuit associated with the line pack.

Two switchboards can be combined and made to handle as many as 29 lines by stacking one switchboard on the other and connecting them with a jumper. To serve more than 24 lines,

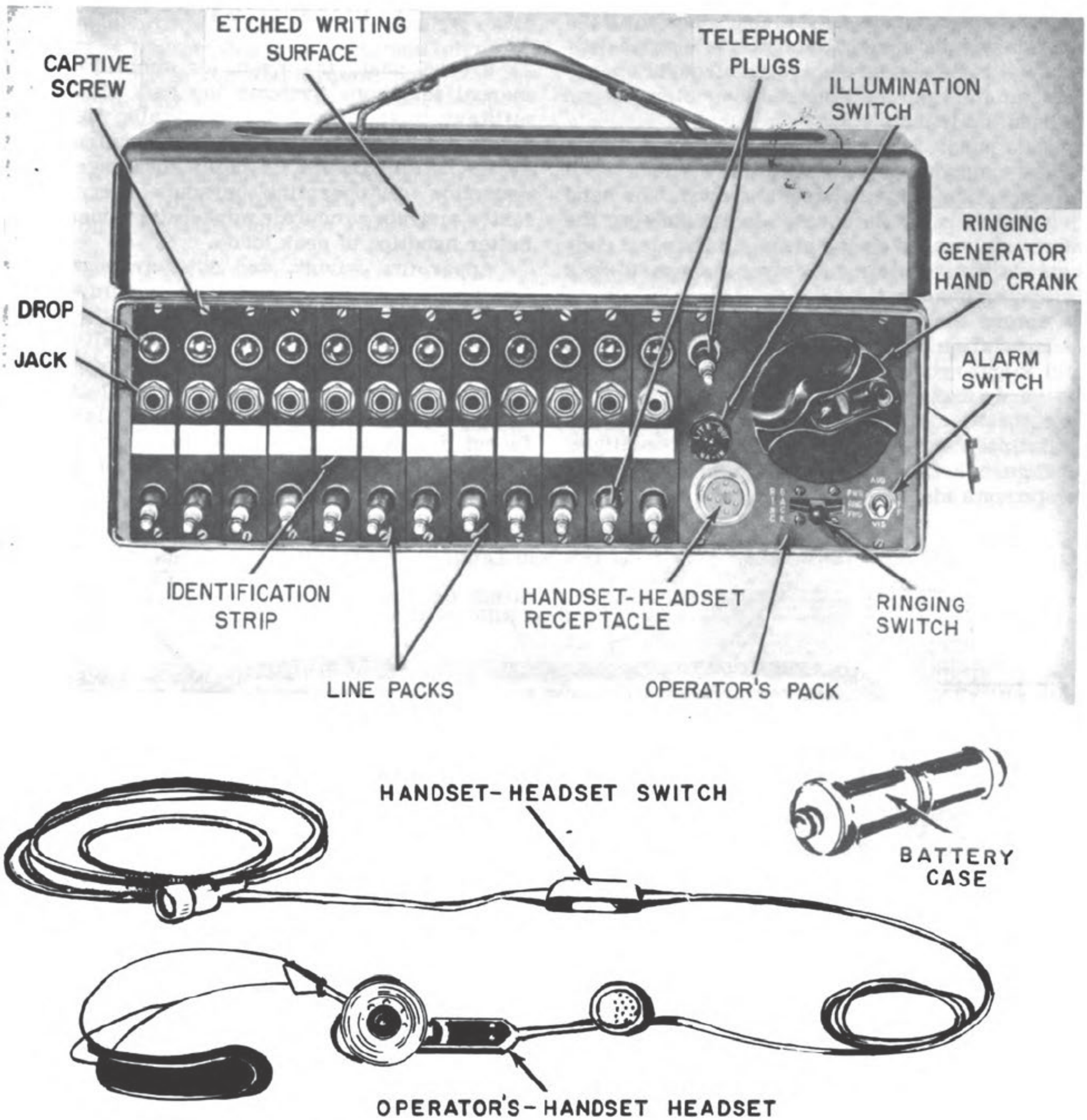


Figure 8-19.–SB-22/PT manual telephone switchboard.

one operator's pack may be removed and replaced by five line packs.

Figure 8-19 shows the SB-22/PT switchboard. You can see the 12 line packs, the identification strips, the operator's pack, and the various switches.

TA-312/PT Set

The TA-312/PT set can be used either in the field, or as an indoor desk or wall set. It is more complex than the simple handset, which consists of transmitter, receiver, switch, and built-in battery.

The carrying case of this set contains all the necessary equipment. Two batteries, or a 3-volt external battery source, are required for operation. In emergencies, the receiver element can be used for transmitting.

The panel and housing assembly contains all the components and necessary wiring, with the exception of the handset and cord. The hand ringing generator is mounted in the housing; the other components on the panel. The handset consists of transmitter, receiver, press-to-talk switch, and handset cord.

Before installing this set, check it for proper operation. Do not install it where extreme cold might reduce the battery voltage, or cause the handset cord and other rubber parts to become brittle. In hot, dry areas, protect the installation from dust and from direct sunlight.

Figure 8-20 shows a TA-312/PT set, with components identified.

DIAL SYSTEMS

In the past, the need for mobility made manual telephone systems the best choice for military installations, but continuing developments in the dial system are swinging the scales in its favor. Its chief advantages are: reduction of operating personnel necessary; faster and more accurate work in disconnections; better handling of peak loads.

Apparatus, wiring, and other arrangements for dial installations vary from system to system. An explanation of the various systems (cross bar, step by step, rotary, all relay, and panel) would be beyond the scope of a training manual for the Construction Electrician service ratings. The instruction manuals for different systems, and the experience of higher-rated men, will be your best source of specific information.

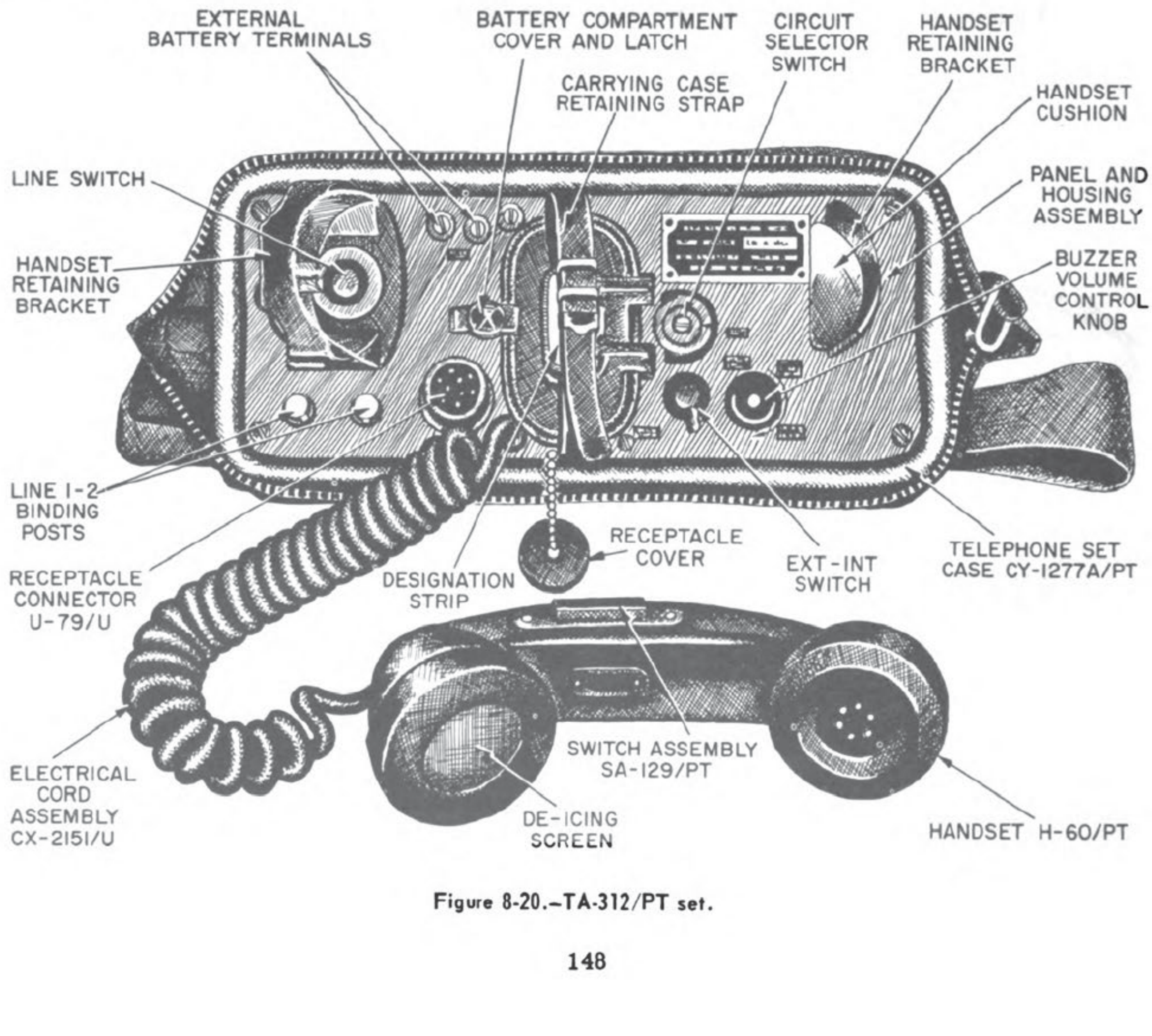


Figure 8-20.—TA-312/PT set.

As far as actual interconnection service is concerned, a dial telephone provides the same service as that obtained from a manual telephone set. The link in the dial system performs the same switching operation as the operator performs in a manual system. However, the interconnections are made differently; and with an automatic switchboard, a dial system can handle heavy traffic that would cause delay and mistakes on a manually operated switchboard.

Connector Banks

Since there is no operator to complete connections between the jacks on the board, some device has to be supplied. The dial systems, therefore, have connector banks, to automatically make connections between subsets. The wires from each telephone, instead of terminating at a jack on the board, terminate at the connector bank.

Figure 8-21 shows how the talking connection is established through the linefinders and connectors of the links, for 30 lines in groups of 10; one wire is used to represent each line.

Connector Switch

Each telephone in figure 8-21 is connected to a wiper (or brush), which is part of a device called the connector switch. It performs the mechanical motions necessary to make the connections between subsets. These wipers are rigidly mounted on a shaft placed in front of the connector bank.

Electromagnetic devices, actuated by impulses, provide lifting and rotating power to move the shaft in a step-by-step vertical motion, and a step-by-step rotary motion in a horizontal plane. Ratchet and pawl assemblies impart these

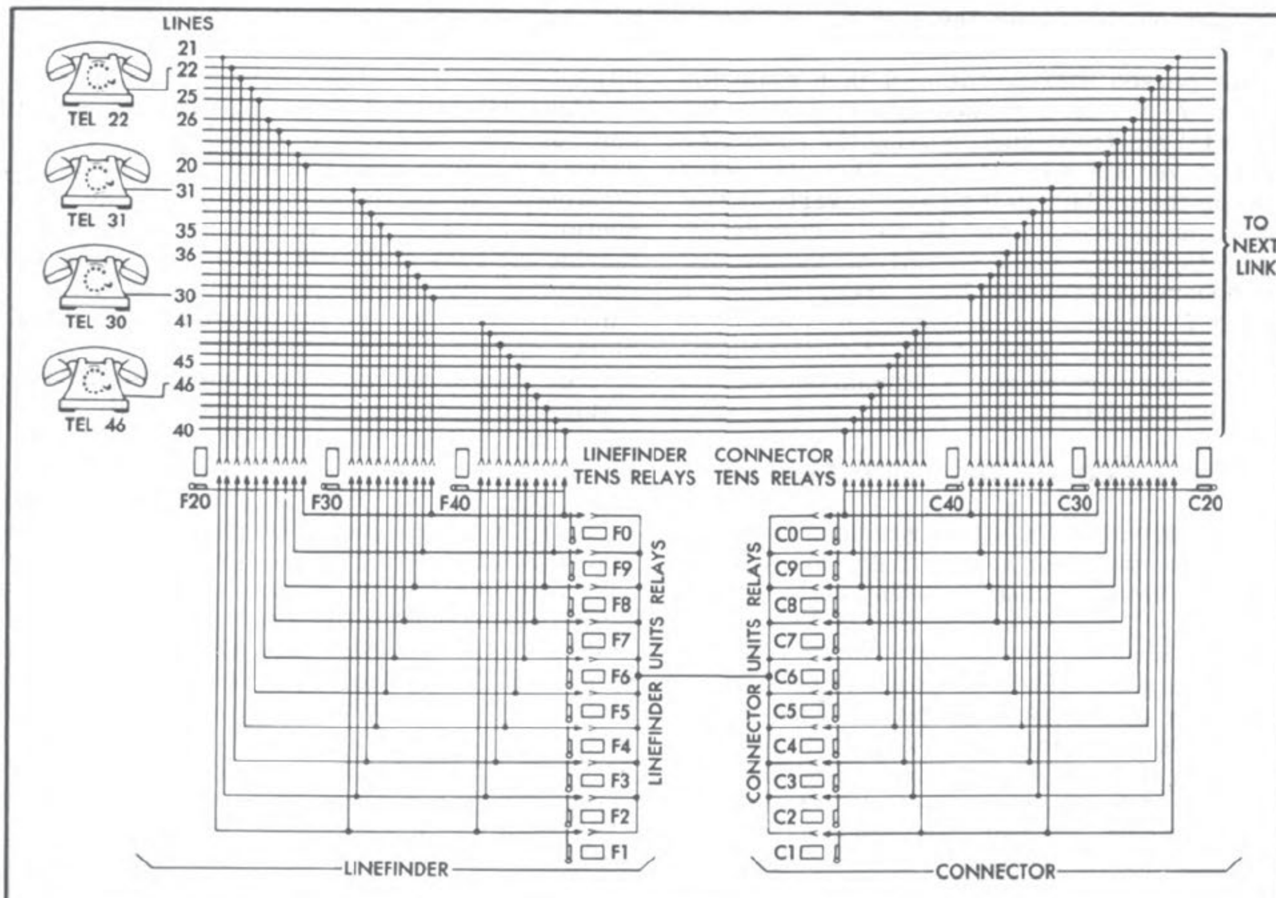


Figure 8-21.—Simplified schematic diagram of a link.

vertical and rotary motions to the shaft of the connector switch.

The necessary impulses are produced by a dial mechanism mounted in the base of each subset. The sequences that occur in the completion of a call through a link in a 100-line system are shown in figure 8-22.

The person using the telephone really controls the action of the automatic switchboard. All that he sees is a dial plate, with finger holes spaced around the rim. When the dial is in normal position, the identifying number for each hole is visible.

Suppose a person at subset 14 wishes to call subset 87. He puts a finger in the hole numbered 8; turns the dial as far as it will go; and then lets the dial return to its normal position. In doing so, the dial operates a cam that opens the impulse circuit eight times; and eight impulses are thus sent to the connector switch. These impulses cause the vertical electromagnet to move the shaft upward by eight steps, and places the wiper on the eighth level of the connector bank.

The person making the call then dials the number 7. Seven impulses are sent over the horizontal electromagnet, moving the connector switch seven steps to the right. This places the wiper on the contact in the seventh vertical row of the connector bank, and the call is completed.

In effect, the cord circuit of the manual switchboard is replaced by a circuit through a linefinder switch and a connector switch. In place of the line jacks of the manual switchboard, jumpers complete the circuit between the telephone substations.

INTEROFFICE COMMUNICATIONS SYSTEMS

Communications systems are used to transmit orders and information among offices only a short distance apart, often in the same building.

These systems are usually installed by men who have a good knowledge of electronics. However, at a base where there are no Electronics Technicians available, the Construction Electricians will have to install any intercommunications systems that are required. By studying the wiring diagram that accompanies the set, a CE should be able to make the installation without any great difficulty.

A system consists of one or more master stations, a junction box, one or more remote speaker units, and the necessary wiring. Each station has a capacity of 12 remote speaker-microphone units. The parts of a station are: a 3-tube chassis, speaker microphone, and selector switch panel.

The switch panel carries selector switches (with station identification), with an annunciator mounted above each switch. Switches have three positions, ON, OFF, and a third position that can operate the annunciator on a remote MASTER STATION unit.

The junction box, used for interconnections to remote stations, is attached to the chassis by a flexible cord. An a-c power cord is also attached to the chassis.

Installation

The master station should be installed within reach of a power outlet operating on 110 to 125 volts, at from 50 to 60 cycles. Ordinarily, the master station and the speaker microphones will be placed on desks, but if any units are installed outdoors, take precautions to give them protection against adverse weather conditions.

Make all connections to the master station unit on the junction box. Solder the joints where the wires are wound to their respective terminals on the terminal strip. Make connections to speaker microphone units by removing the back of the cabinet and attaching the connecting wires to the terminal screws. Attach annunciator wires to the pushbutton terminal block.

The length of wire that must be used in making connections between units will govern the size of wire that you choose. For example, No. 22 wire gives a resistance of 32 ohms per 1000 feet, and No. 19 wire gives a resistance of only 16 ohms per 1000 feet. You should therefore use No. 19 when long stretches of wire are necessary to connect the units.

In the annunciator lines, wire resistance must be kept below 15 ohms per pair. It will be best to use No. 14 wire (4 ohms resistance per 1000 feet), or No. 16 (8 ohms resistance per 1000 feet).

Never carry interstation wires across hot pipes, nor place them in any location where they might become covered by water.

After you have installed all wiring, check the resistance with an ohmmeter. This will indicate whether there are open circuits, grounds, or shorts, as well as showing whether the permissible resistance has been exceeded.

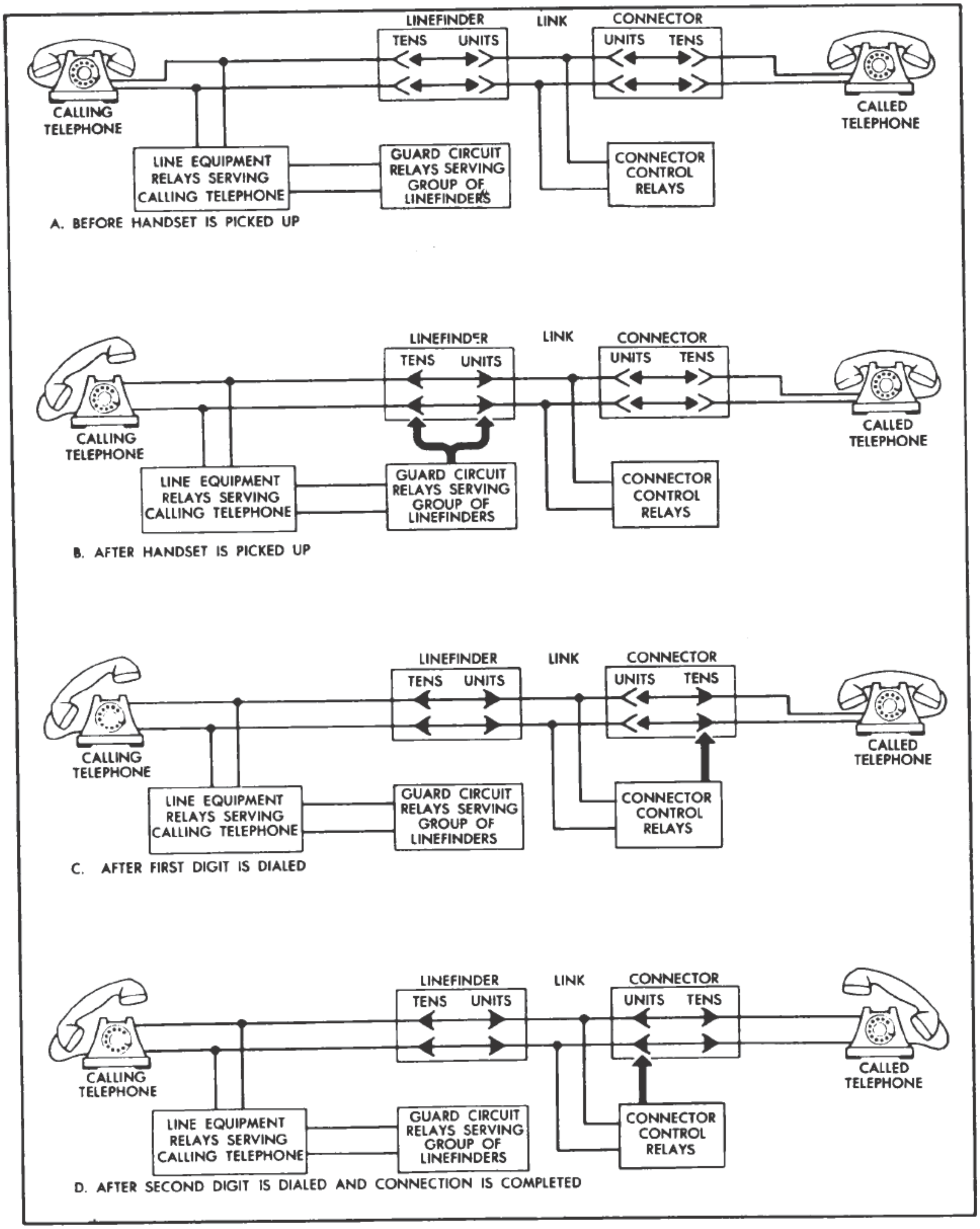


Figure 8-22.–Diagram of the sequences in a completed call through link, 100-line system.

Operation

When the button on a remote speaker-microphone unit is depressed, or a switch thrown at a remote master unit, a buzzer sounds at the master station, and the annunciator for the calling station springs outward. When the selector key is raised to answer the call, the annunciator should be pushed back to its normal position.

The talk-listen lever has three positions—IDLE, LISTEN, and TALK. If the system has only one master unit, press the lever into the TALK position, to complete a connection with a remote speaker-microphone unit. If there is more than one master unit, put the lever in the IDLE position before throwing the selector switch of the station to be called. Then, if the called station is in communication with another station, you will be warned; if it is not, press the lever into the TALK position to complete the call.

PUBLIC ADDRESS SYSTEMS

During the early stages of an invasion, portable types of public address systems are used to amplify speech in the landing area. Small types are d-c battery powered and are completely self-contained. When great sound coverage over a high level of noise is required, a large a-c portable type, powered by a gasoline driven generator, is used.

At an established base, a public address system may be used for an auditorium, outdoor movies, or for camp communications. During World Was II, a talk-back type of system was established for camp communications. Horns serving as loudspeakers were placed at strategic locations around the base. A called station could answer the master station if the speaker stood within about 30 feet of the loudspeaker.

The talk-back type is seldom used today. The system generally used for advanced base communications is a portable set consisting of a 100-watt cabinet-type amplifier, a dynamic (movable coil) microphone with heavy-duty floor stand, two 25-foot lengths of shielded microphone cable, and one 25-foot length of heavy-duty power cable. This system requires 100/125 volts on 50/60 cycles.

The horns serving as loud speakers can be controlled individually or in any combination. The speaker can address only one station, a few stations, or all stations. A changeover switch is provided to allow signal input from either a microphone or a phonograph.

As with any electrical circuit, the wiring diagram provides the key for the proper wiring connections. Normally, No. 14 size wire should be used for wiring connections. The horn loudspeakers may be mounted on top of buildings, on poles, on speaker stands, or even in trees. Before making the location of the loudspeakers permanent, it is desirable to test for uniform loudness, for minimum echo, and for dead spots. Follow the recommendations of the manufacturer closely when you make the installation.

MAINTENANCE AND REPAIR

The best equipment will occasionally show faults in service. In addition, maintenance of an installed system may sometimes involve the adding of new circuits, the placing of cross connections, the installing of local switchboards, and similar changes and rearrangements. You will find, therefore, that maintenance is more than a matter of correcting the effects of dirt, moisture, or wear.

On the other hand, it is equally true that preventive maintenance—as represented by routine tests and periodic inspections—will be a major step in cutting corrective maintenance requirements to a minimum.

This section contains some practical suggestions on the maintenance procedures to be used in regard to batteries, wiring, and switchboards. There are also some helpful suggestions for dealing with troubles that arise in intercom and public address systems.

Batteries

Inspect the containers for dirt, dust, or cracks. Clean them with a dry cloth, never with a damp or wet cloth.

Examine the terminals and the straps between the cells for tightness or corrosion. If the terminals need tightening, do not use too much force, as you may damage the connections. Remove corrosion with sandpaper or crocus cloth.

Remove the seal from a cell as follows: Have a wooden trough ready, with uprights between which the cell is placed. The overhanging cover should rest on the top of these uprights; and the bottom of the trough should be covered with corrugated cardboard, so that when the jar drops, after unsealing, it will not crack. Unseal by running a knife blade between cover and jar.

Check the electrolyte for level and for specific gravity. The level should be at the upper red line on the jar. In checking specific gravity, use a pilot cell; change this cell after 50 readings. Too low a specific gravity is indicated by plates that are lighter or darker than the surrounding cells.

For storage batteries, the voltage should be at least 22 v, but not more than 30 v if the batteries are charged during use. Violent gassing and temperature rise in the electrolyte indicate that the charging current is too high.

Be careful of possible fire hazards in the vicinity of batteries. Poor connections can be very dangerous, because of the sparking they may cause. AT ALL TIMES, keep cigarettes or open flame, however small, away from batteries.

Circuit Faults

All circuits should be tested at regular intervals. Wiring diagrams will be a great help to you when you are trying to locate circuit faults. If you find that there are no broken wires, nor faulty connections, you will have to locate the source of trouble by continuity, voltage, and resistance measurements. Start at a point where the circuit is known, and eliminate parts of the circuit, step by step, until you have located the fault.

Wiring

Most of the maintenance on wiring, as opposed to subsets and switchboards, will be corrective rather than preventive. Of course, you will have to inspect terminal boxes for broken lugs and defective faceplates; and you will check drop wires to make sure that insulation is satisfactory, support adequate, and connections (especially of unused pairs) finger tight. Most of your maintenance time, however, will be spent in locating and repairing grounds, open circuits, and shorts.

If the signal lamp on a switchboard lights continuously, a ground is indicated. Check the ring line (or tracer wire) first. Place the receiver of your test telephone in series with the tracer line at the nearest terminal box. If you hear a sharp click, move to a point nearer the defective telephone. When you fail to receive a click, you know that the ground is between this point and the one previously checked.

When the ground is in the plain conductor, or tip line, there will be noise on the circuit, because of ground returns of other currents. Disconnect the tip line from its terminal at the pole, and then attach your test receiver leads to the ring line and to the portion of the tip line that leads to the defective telephone. A click indicates that the ground is between you and the subset. Keep moving toward the subset until you fail to receive a click. This tells you that the ground is between this point and the one at which you made the previous test.

The diagrams in figure 8-23 indicate how to test for a ground on a tracer or ring line, and for a ground on a tip line.

When you are looking for an open circuit in one of the pairs of wires, go to the terminal box which is closest to the central office, and which has terminals tapped to the pair of wires to be tested.

Connect the leads of your test telephone across the proper terminals; one lead should be clamped on, the other just tamped against the terminal. If you fail to receive a sharp click, one line is dead in the aerial cable. This will require splicing. If you hear a very faint click, do not consider this an indication of battery voltage, since it is probably caused by a slight difference in ground potentials.

If you hear a sharp, definite click, you can be assured that battery voltage is present up to that point, so your next point of testing will have to be the terminal box to which the drop wire is connected. A sharp click on your test receiver at this point indicates that the open circuit is in the drop wire or in the inside wiring.

The dividing point between drop wire and inside wire is the protector, so make that the next testing point. If no click is received when you place the test leads across the protector, the open is probably in the drop wire. Perhaps an inspection will indicate the break, and you can splice the wire; otherwise, it may be necessary to replace the whole drop wire.

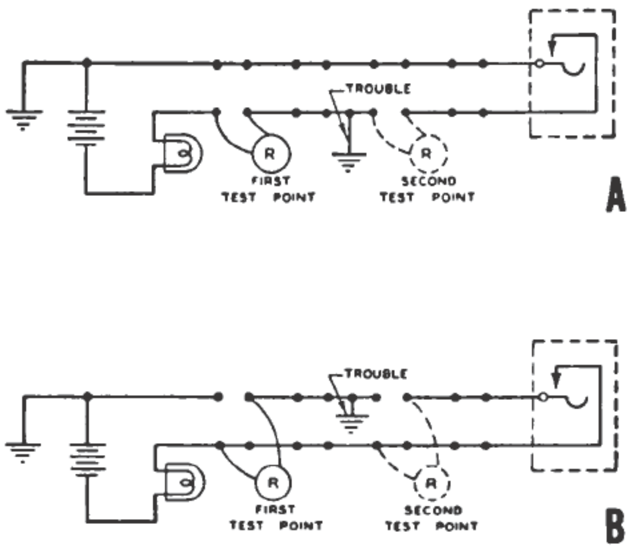


Figure 8-23.–Testing for a ground: A, ring line; B, tip line.

To determine if the ground line at the protector has an open, use your test telephone leads where the pair of wires comes into the protector, by attaching one lead to the ring line, and tapping the tip line with the other lead. If you receive a click, tap the ground line (instead of the tip line) with the second lead. A click indicates that the circuit is good to ground; absence of the click indicates an open.

To locate a short, go to the first check point and place your test receiver in series with the tip line. A click indicates that you are between the short and the central office, so keep working along the drop line until you fail to receive a click. At that point, you are beyond the short, so you know it lies between the last two points that you tested.

Subsets

The first step in checking a subset is to verify the trouble. It may be as slight as a loose connection, or iron filings around the ringer magnet.

You should know the telephone number and the location of the subset, the cable pair number, the location and number of the cable terminals, and the location and number of the cross-connecting box, if any. It will help to have access to any previous trouble reports, since they may give a clue to the cause of the present trouble.

Maintenance usually can be divided into correcting troubles that lie between the central office and the subset, and troubles that lie in the subset itself.

A good point at which to begin, for troubles outside the central office, is at the main distributing frame. As you remember, this is the dividing point between outside plant and inside plant, and is the location of the central office protective devices.

Check the protector (where drop wire connects with inside wire); look for moisture; check for broken, defective, or loose fuses; replace badly pitted carbon blocks; check the ground wire.

At the subset, examine the transmitter for cracks or breaks in the mouthpiece; for missing rim screws or loose contact springs; for dirt or moisture. Look for dirt, corrosion, moisture or cracks within the receiver. Examine the mounting of the ringer, and look for dents or cracks in the coils. Observe the contact and lever action of the hook switches, and look for rusty, bent, or pitted springs. Check to see that stay cords and hooks are secure.

The main thing is to put the line back into service as soon as possible, so for considerable repair, replace the subset and send the defective one back to the shop.

Switchboards

Inspection, tightening, cleaning, and adjusting are the basic operations in switchboard maintenance. Periodic inspections are of the utmost importance, since a minor defect may not at once interfere with the performance of the equipment, but may lead in time to a major breakdown.

Every day, the switchboard exterior should be wiped off with a soft, dry cloth. The batteries, headset, chestset, and exterior of the distribution frame should be inspected. Chipped paint, mildew, corrosion, must be removed, and the storage batteries checked for electrolyte level. Do not forget to inspect the wiring on the rear of the panel.

A weekly inspection should be given to cords, keys, shutters, fuses, protector blocks, heat coils, repeating coils, and ground rods.

Inspect the cords for dirt, dust, or fungus. Check the cord weights and pulleys for smooth operation. Wipe the cords with a clean, dry cloth.

Adjust the shutter latches, using long nose pliers, and then test them to see if the shutters fall freely when a call is received, but remain in place when the switchboard is jarred.

Make sure that fuses are of the proper capacity, and tighten the fuse mounting screws.

Remove dust, dirt, or other foreign matter from the protector blocks, and replace porcelain or carbon blocks that are chipped or broken. Use care in cleaning, because if you dislodge a block, you can cause trouble on an incoming line.

Inspect heat coils for cleanliness, and replace any that show chipped or broken coils. Do not remove the covers of repeating coils, but examine the mountings for loose, damaged, or missing screws. Clean the coils with a dry, clean cloth.

Look for any rust or corrosion on ground rods. Check to make sure that the wing bolt at the terminal connection is tight.

Plugs, relays, capacitors, terminals, binding posts, and cables, should be given a monthly inspection. Clean the switchboard plugs with cord plug polish, using a clean, dry cloth. Remove all residue of the polish after cleaning in order to maintain good electrical contact.

The relays and capacitors need to be inspected only for dirt and foreign matter. Clean them with a dry cloth.

Inspect the terminals and binding posts on the switchboard and control panel for cleanliness and tightness. Check the incoming line connections for good electrical contact. Tighten any loose terminals with a suitable screwdriver or wrench. Clean the terminals and binding posts with a soft bristle brush.

Examine connecting cables for damaged or worn insulation. Check the fittings on the ends of the cables for tightness and good electrical connection. Tighten the connections on the cables as required.

Intercom Systems

In general, maintenance procedures for switchboards apply equally well to interoffice communications systems. The four steps—inspect, tighten, clean, and adjust—are all important, with inspection being of primary importance in the maintenance program.

The components in an intercom set are all readily accessible, and for the most part they can easily be replaced when they are found to be faulty. However, you have to use your knowledge of the working principles of the system, to be sure that the defective part is the cause and not the result of trouble in the system. For example, you might replace a burned-out transformer or resistor, only to find that the replacement burned out also, because the actual trouble was located elsewhere in the circuit.

Public Address System

Oftentimes, trouble in a PA system is due to nothing more than a loose cable connection, or a break in the cable shield. Before commencing lengthy tests, check for faults of this type.

In soldering connections make sure that both metals are clean; the completed soldering job should be firm and durable. Faulty soldering can cause faults in the system that are very difficult to locate.

Serious troubles in the system require signal tracing equipment such as an audio signal generator and an output meter or an oscilloscope. In testing the electric circuit, the most important point to remember is that the trouble should be localized and isolated. A careful study of the circuit diagram will save much unnecessary testing.

Tools, Material, Equipment

With field telephone sets, the tools and equipment that you will need for maintenance and repair are included as a part of the component. For subsets taken out and sent to the shop for repair, the maintenance tool is the same test telephone that you use in locating shorts, opens, or grounds.

In general, you should have the following equipment at hand before starting any cleaning or repair procedures: test telephone; clean, dry cloths and soft bristle brushes; a dry cleaning solvent; cord polish; a crocus cloth or No. 0000 sandpaper; screw driver set; long nose pliers; wrench sets, both open and socket; and a battery hydrometer.

QUIZ

1. How can the normal talking range of a field wire installation be extended?

2. In the type of carbon transmitter commonly used to amplify the energy of entering sound waves, the basic circuit consists of battery and

   (a) carbon chamber, diaphragm, and induction coil
   (b) magnetic diaphragm
   (c) moving conductor
   (d) carbon chamber and electrodes

3. What is the function of the reciever in a telephone subset?

4. In a field telephone installation powered by a common battery system, the energy for the signaling current is provided by

   (a) a separate circuit powered by a dry cell
   (b) a small hand generator connected to the talking circuit
   (c) a ringing machine attached to the power source
   (d) small storage batteries located at each substation

5. In a common battery system, how must stations and battery be connected?

6. What is the purpose of having a special anti-sidetone circuit between two telephone sets?

7. The voltage and frequency of a hand-operated generator used in a telephone circuit to provide a signaling service can be increased by

   (a) including an induction coil in the talking circuit
   (b) increasing the speed of cranking the generator
   (c) inserting two soft iron electromagnets in the ringer circuit
   (d) connecting a resistor to the negative terminal of the power source

8. What is the primary reason for keeping field wires to minimum length in telephone line construction?

9. To offset the sway of trees used as support for aerial wires, you should guard against the risk of broken wires and consequent interruption of service by

   (a) installing a double set of wires
   (b) installing insulators to which the wires can be tied
   (c) providing guy lines as additional support
   (d) providing for a sag that is slightly more than normal

10. The primary use of a trunk or tie cable is to provide facilities for

    (a) installing new circuits
    (b) sending and receiving calls at local switchboards
    (c) connections between two narrowly separated exchanges
    (d) connections between two widely separated exchanges

11. What are the 2 methods of fastening a cable to a suspension strand?

12. In laying buried cable for a communications system, what should you do with the final length of wire when a reel runs out?

13. How are connections between subsets and main run made in a pole-mounted terminal box?

14. When several telephone stations are connected by means of a switchboard, how are the lines interconnected?

15. In addition to battery case and handset-headset, the switchboard assembly for a 12-line circuit includes 36 binding posts, 12 line packs, and

    (a) a main distribution frame
    (b) a power panel
    (c) an operator telephone circuit
    (d) one or more trunklines

16. What two purposes are served by a distribution frame?

17. Cross-connections between the horizontal and vertical sides of a distribution frame are made by means of

    (a) cords fitted with plugs
    (b) line jack telephone circuits
    (c) operator's pack
    (d) jumpers

18. Central office protective devices are usually located on the

    (a) air gap arresters
    (b) main distribution frame
    (c) power panel
    (d) switchboard

19. A heat coil is a practical device for protecting a switchboard against
    (a) accidental current surges
    (b) lightning
    (c) continuous excessive voltage
    (d) continuous excessive current

20. What are the functions of cord circuits on a central office switchboard?

21. What are the 3 positions of the switch key as a switchboard operator makes the required connection between two lines?

22. On an open wire system, where the main run is strung on cross arms, connections between subsets and main run are made by means of a
    (a) terminal box
    (b) drop wire clamp and cable ring
    (c) tap to designated wires from the cable stub
    (d) direct tap to the open wires

23. In what way do fuses and lightning arresters protect telephone sets from the hazards of crosses with light and power lines, and of lightning discharges?

24. When you are routing inside wiring from protectors to subset locations, in what direction should you make the run?

25. The wire which must always be connected to the right-hand terminals of protectors and connecting blocks is the
    (a) ringer wire
    (b) hook switch
    (c) tracer wire
    (d) tip line

26. Name 2 low-voltage sources that can be used to energize a bell circuit.

27. Which of the following telephone sets can be used either as a field or indoor set, and can operate on a 3-v battery source?
    (a) SB-22/PT
    (b) TA-312/PT
    (c) TC-2
    (d) TC-10

28. In a dial telephone system, what device takes the place of switchboard jacks as terminal points of the wires from subsets?

29. In a dial system, what sequence of steps actuates the shaft to which the wipers are attached?

30. What is the purpose of the third position of the switches on the selector switch panel of an intercom system?

31. All connections to the MASTER STATION unit of an intercom system should be made on the
    (a) speaker microphone units
    (b) selector panel
    (c) junction box
    (d) pushbutton terminal block

32. The maximum number of times you should use the same pilot cell for checking specific gravity of batteries is
    (a) 10
    (b) 25
    (c) 50
    (d) 60

33. In checking for an open circuit at a termnial box, a faint click on your test receiver indicates
    (a) normal battery voltage at that point
    (b) a slight difference in ground potential
    (c) an open in the drop wire
    (d) an open in the inside wiring

CHAPTER 9

TELEPHONE CABLE SPLICING

All lines, whether for telephone or for power distribution, require some splicing. The length of cable on a reel is seldom the same as or less than the length of cable to be installed. Even after a system has been installed, there will always be a certain amount of splicing necessary to take care of repairs on defective cable sections, or of additional sections that must be spliced to the main cable.

Telephone cable, used as it is chiefly for aerial installation, is seldom spliced underground, whereas splicing on power lines will always be done in vaults and manholes. The usual methods for joining cables used for underground distribution of power have been described in chapter 6 of this training course. The methods of splicing in cable terminals for telephone lines have been described in chapter 8. This present chapter, therefore, is limited for the most part to a discussion of the methods by which the aerial cables are to be spliced.

CABLE TERMINOLOGY

Before going into the methods of telephone cable splicing, you should know exactly what is meant by the terms used to describe cables, and the terms used to describe the various types of splicing.

Cable for telephone communications may be classified as aerial, buried, submarine, and underground. The greater amount will be aerial cable, but there is always some underground cable in communications systems, and there is likely to be some buried and some submarine cable.

Aerial cable, as you know by now, is lead-covered cable suspended on poles. Buried cable is underground cable that is used without conduits; it therefore comes into contact with earth. Tape-armored (or jute protected) cable is the type most often used for this purpose. Regular underground cable is protected by being installed in conduits. Submarine cable is a wire-armored type that is practical for sections that must be carried through swampy land, or through lakes or rivers.

You should also know, that while the size of power cable indicates its power-carrying capacity, the size of telephone cable indicates the number of pairs of conductors in the cable.

Classification of Cables

Outside cables for telephones, like power cables, are usually lead sheathed. However, the wires inside the cable are insulated with paper. The insulation may be sprayed on in the form of pulp, or the paper may be wrapped spirally about the conductors. Double-wrapped wires provide a high dielectric (nonconducting) insulation, both because of the additional thickness of the paper, and the added air space. This higher insulation is a protection against insulation breakdown that might be caused if an open-wire telephone line should come into contact with a power line.

In general, the classification of cables is as follows: tape-armored cables, building and switchboard cables, and plastic-covered cables.

Tape-Armored

Tape-armored cable is a lead-covered cable fitted with a protective covering of paper, jute, and steel tape. This tape can be obtained to match standard lead-covered cables. Its advantages are that it protects the cable against damage by rodents, and against mechanical injury, when it is necessary to install the cable in the ground, without conduits.

Lead-covered cable can be further classified as quadded, color coded, and composite cable.

In quadded cable, some of the conductors (or perhaps all) are arranged in quads; that is, in groups of TWO PAIRS.

Where outside cable contains 51 or more pairs of conductors, they are color coded according to groups. This simplifies matching them when they are to be spliced.

Composite cable signifies cables that include two or more sizes of conductors.

Building and Switchboard

Building and switchboard cable is the type used to make connection with the service conductors, and to connect the switchboard apparatus to the main distribution frame. It may also be used for local wiring in the switchboard.

Switchboard cable is made up of copper, or tinned-copper, conductors with a silk and cotton insulation. You may also obtain it with a black enamel insulation. The pairs of conductors are usually bound together with a spiral layer of paper, a layer of lead tape, another layer of paper, and a fireproofed braid. For color-coded cable, the insulation is colored in accordance with a standard color scheme, so that each pair of wires, and each unpaired single wire, can be identified. This color code is given in appendix II of this text.

Plastic-Covered

Cable with plastic covering represents a fairly recent development, but one that is increasing in importance. It has the advantage of being light in weight, which makes it especially suitable for use at advanced bases. Then, too, lead is a relatively scarce material, and expensive; a satisfactory substitute would find ready adoption.

Procedures for splicing plastic-covered cable closely parallel those that are used for lead-covered cable. Techniques are undergoing improvement, however, so be sure to make use of the manufacturer's manual that will accompany plastic-covered cable.

A recently perfected method of splicing by pressure is discussed later in this chapter, in the section, Resin Pressure Splicing.

Classification of Splicing

The three usual types of telephone cable splicing are straight splicing, bridge splicing, and butt splicing. Figure 9-1 illustrates each of these methods.

In A of figure 9-1, you see the cables coming from opposite directions. The splicing

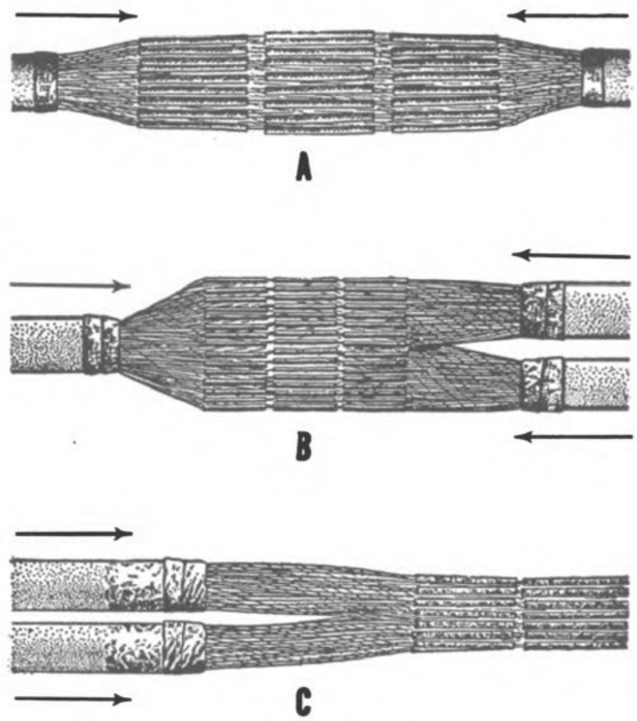


Figure 9-1.—Types of telephone cable splicing: A, straight; B, bridge; C, butt.

of each individual wire is concealed by the small sleeves (cotton sleeves); but the direction from which the cables approach is what leads to the term "straight" splicing. In C of this figure, the wires that have been spliced enter the sleeves from the same direction. In B, you can see that two cables coming from the one direction have been spliced to a cable coming from the opposite direction; this is the type of splicing known as bridge (or branch) splicing.

Straight splicing is the simplest form of splicing, since it consists of joining two wires that approach the splice point from opposite directions. Bridge splicing is employed where it is necessary to accomodate branching of a cable. Most butt splices are made where a flexible arrangement is desired; they may later be changed either to straight or to bridge splices.

SPLICING PROCEDURES

Most of your splicing will consist of splicing the individual wires of two cables. This is the

method know as straight splicing, and is fundamental to all splicing. In this training course, you will find a description of the step-by-step process of splicing the single conductors that make up two cables, of drying out the completed splice, and of beating in (or finishing) the lead sleeve that covers the spliced area. This information should be enough to give you the essentials of the splicing procedure.

For splicing the wires of two cables, you must remove a section of the sheath from the end of each cable; remove any metal protector provided for the cable core; select the individual wires from each cable; splice them in a staggered pattern; cover each splice with a cotton sleeve, to prevent contact between the wires; position a lead sleeve over the completed splices; beat in the lead sleeve to make a tight joint; and wipe the joint.

This is just a brief statement of the operations; the following sections cover each of these operations in detail.

Removing the Sheath

Measure the length of the sheath to be removed, and ring the cable at the point where the cut is to be made. The diagram in figure 9-2 shows a distance of 18 inches, but this is only for the sake of illustration. In every case, the length of the splice opening will depend upon three factors:

1. Size of cable (number of pairs of wires)
2. Diameter of conductors
3. Type of splice

In ringing the cable, be sure that the cut, or score, does not penetrate completely through the sheath. There is always the chance of damaging the conductors of the cable. The scored or ringed point is your indication of the limit to which the sheath is to be removed.

Clean the sheath for about 4 inches back from the ringed point; this distance is indicated in figure 9-2 by the section between A and B. This 4-inch area must be thoroughly cleaned; if dull or dark streaks are left, they will not tin, when the wiping operation is done later. As a result, the joint will be defective.

Use a file cleaner for cleaning the sheath on new cable; on old cable, you will do better to use a shave hook.

Immediately upon cleaning this area, and before your hands have touched it, coat it with stearine, and wrap it with a double layer of

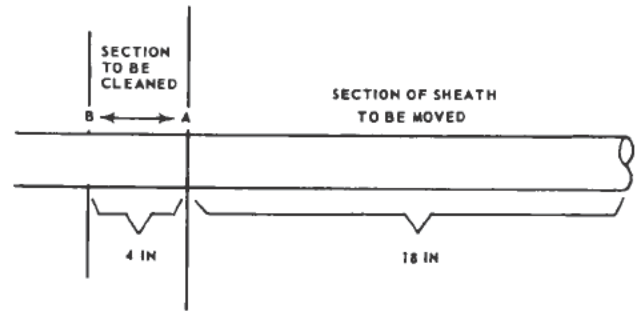


Figure 9-2.—Preparing the cable for splicing.

boiled-out muslin. You do this in order to protect the adjacent area while you are removing the sheath for the splice opening.

With a chipping knife, split the sheath along the distance between the ring and the cable end. You must avoid cutting through the paper wrapping of the cable core, so be careful in driving the knife under the edge of the split, to loosen the sheath.

Grasp the cable at the section where you have wrapped it in the protecting layer of muslin, and gradually work off the split portion of the sheath. It should break off at the ringed point.

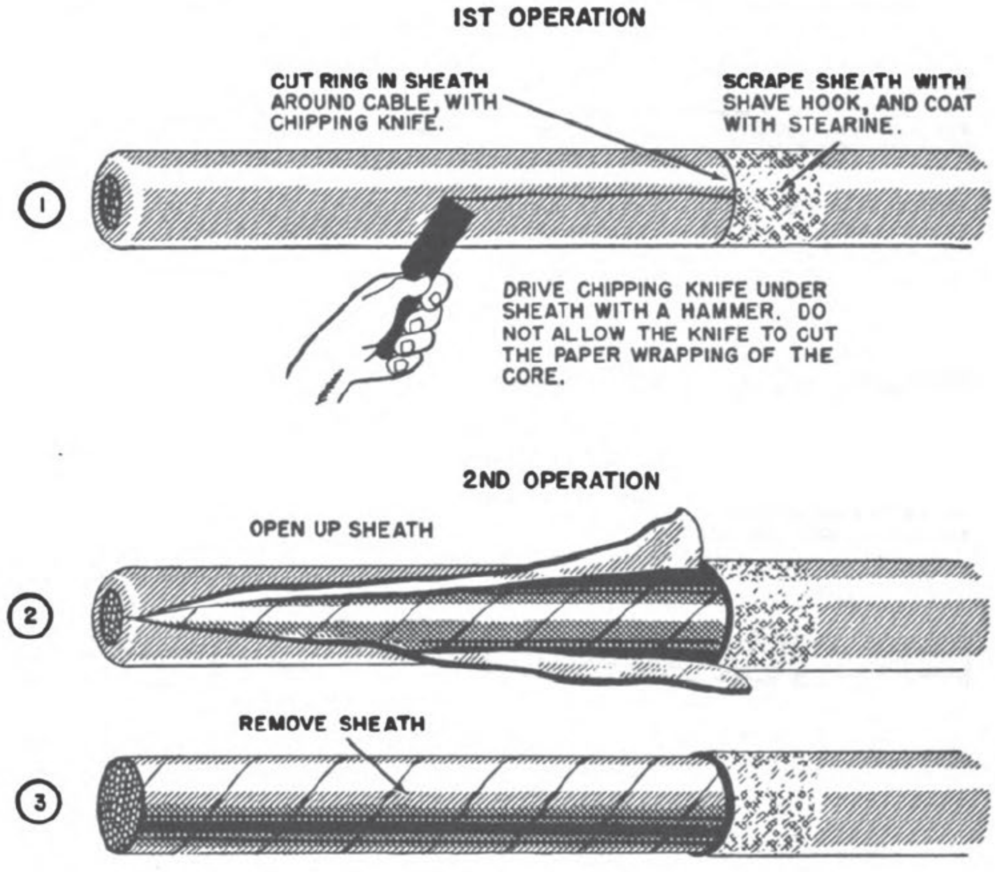
In figure 9-3, you can see the general operation of removing the sheath. In the section labeled first operation, there is no indication of how the section is wrapped in muslin; but other than this, the illustration shows the main steps of ringing the cable, cleaning the sheath and coating it with stearine, slitting the sheath with the chipping knife, and removing it.

Inspect the edges where the sheath has broken off, to make sure that they are smooth. Any sharp edges or burrs left at these points could cause damage to the cable insulation during splicing, when there has to be considerable movement of the cable.

The best way to protect the cable core from sharp edges is to butt the sheath with boiled sleeving, muslin, or cotton tape. In figure 9-4, you can see the method of butting the sheath of small cables. The explanation of the three steps is given in the illustration.

Use of Sleeves

Three types of sleeves are mentioned in this chapter: cotton sleeves, lead sleeves, and split lead sleeves. Get the distinctions clear, so that you will understand the text, in case the adjectives "lead" or "cotton" are not used.



① *Using chipping knife.* ② *Opening sheath.* ③ *Sheath removed.*

Figure 9-3.—Steps in removing the sheath.

Cotton sleeves are used to cover the splices on individual wires; they serve to keep the wires from touching. You will find them referred to in the section, Tying the Wires.

Split lead sleeves are used to cover a break made in a cable for the purpose of repairing defective insulation. These sleeves are discussed in the section, Split Sleeves.

Lead sleeves are used to cover the spliced area in a cable, after all splicing has been done. In commercial use, it is now the general practice to employ an aluminum sleeve for overhead wire. For underground cable, where there is danger of corrosion, a cast-iron sleeve is generally used; and when future splicing is undertaken, it must be done at some other point. At advanced bases, however, you will probably be using lead sleeves for all spliced areas.

You will find it advisable to place the lead sleeve on one of the cables as soon as the sheath has been removed, and the cable ends have been cleaned. Slip the sleeve up the cable, out of your way as you perform the splicing operations. When all the splices have been made, you can then draw the sleeve down over the spliced area.

The only work that must be done on the sleeve is the cleaning, and the inspection for sharp edges. If you notice any indentations, square up the ends of the sleeve with a lead file, before you slip it on the cable. The beveling, or beating in, is not done, of course, until the sleeve is brought down into its final position.

The size of the sleeve that you will use is determined by three factors: size of cable; size of the conductors; and type of splice. In appendix II of this training course, there is a table showing the proper sizes of cotton sleeves to use on conductors of specified diameters.

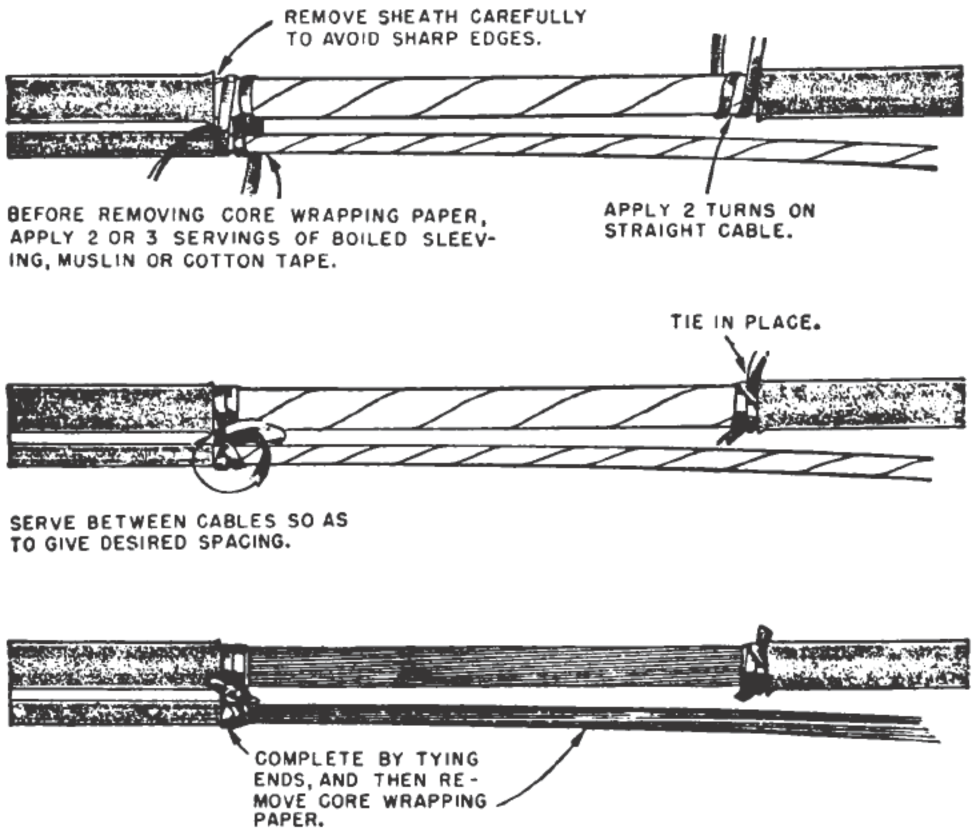


Figure 9-4.—Butting the sheath of small cables.

Removing the Insulation

Boiling out the insulation in the area where the splicing will be done serves to remove any moisture that may be present. It will also make it easier for you to remove the paper insulation from the individual wires, when you are ready to splice them; and it will prevent the paper insulation from unfurling or running back.

The removal of moisture, and prevention of moisture reentering the break, are of first importance, since the effectiveness of the insulation is determined in part by DRYNESS. Therefore, if the splice is left incomplete over night, or if you are working in a very damp atmosphere, you may have to go through the boiling-out process several times.

Discoloration of the insulation, and a bluish-green discoloration of the conductors, will be a sure sign that excessive moisture is present. If only a small amount of moisture has seeped in, the insulation (but not the conductors) will be discolored.

In the boiling out process, the paper insulation will be damaged if the paraffin is applied at a temperature higher than 390 F. Do not heat it above 375 F. If you do not have a thermometer capable of registering these high temperatures, you can apply a practical test to the paraffin when it is heating. Watch the dry ring that forms, and gradually creeps up on the outside of the pot. This ring will form when the paraffin is at about 360 F; when the ring is about 2 inches at its widest point, the paraffin has reached the proper working temperature.

Pour the hot paraffin over the sheath, starting about 6 inches back from the exposed wires. You may ladle it from a deep container; use a large shallow pan for catching the drip. Gradually work the stream of paraffin onto the paper insulation, and out to the end of the wires. The paraffin forms a seal that excludes the entrance of moisture.

When you are splicing large cables, it is advisable to again boil out the cable, as soon as 200 pairs have been spliced. By that time, the

insulation will have begun to absorb moisture from your hands, or from the atmosphere, and this boiling out process will remove such moisture. (Remember that paper insulation has a tendency to absorb moisture; do not leave a cable core exposed for any length of time either before it is boiled out, or after it is boiled out.)

The paraffin method has the disadvantages of involving a certain amount of fire hazard, and of generating objectionable fumes within the building. It is a possible cause of burns to the men using it, and it is likely to splash on floors or walls. The newest method, therefore, is to dry out the insulation with some type of drying agent, usually referred to as a DESICCANT. The usual desiccants employed are anhydrous calcium sulfate and silica gel. Where hot paraffin drives out the moisture, a desiccant absorbs it.

If a desiccant is available, sprinkle it in generous amounts among the conductors, after the wire work has been completed. Enclose the splice first in a muslin envelope, long enough to overlap at both ends of the splice. Open one end, and let the desiccant trickle in; spread the conductors apart with your fingers, to allow for good distribution. You may have to replenish the drying agent from time to time.

Tying the Wires

The pairs of wires are arranged within the cable in color groups, with the low count at the center of the core, and the higher count outside. This arrangement assists in quick identification. Nevertheless, you should always work from a splicing diagram, or at least from definite instructions.

Lash the cable ends into position, to diminish swaying and to prevent creeping. After the wires have been folded back, in pairs, the cable should look like the illustration in figure 9-5.

Your next step is to grasp a pair of wires from the right-hand splice, and another pair from the left-hand splice, as indicated in figure 9-5, B. Use your left hand on the right-hand splice, if you are right-handed. Hold the wires between thumb and forefinger.

Bring the wires together, and give them a sharp half-turn, as shown in B of figure 9-5. Then, holding both pairs of wires in one hand, cut them about 4, or 4 1/2, inches from the twist, as illustrated in C of this figure.

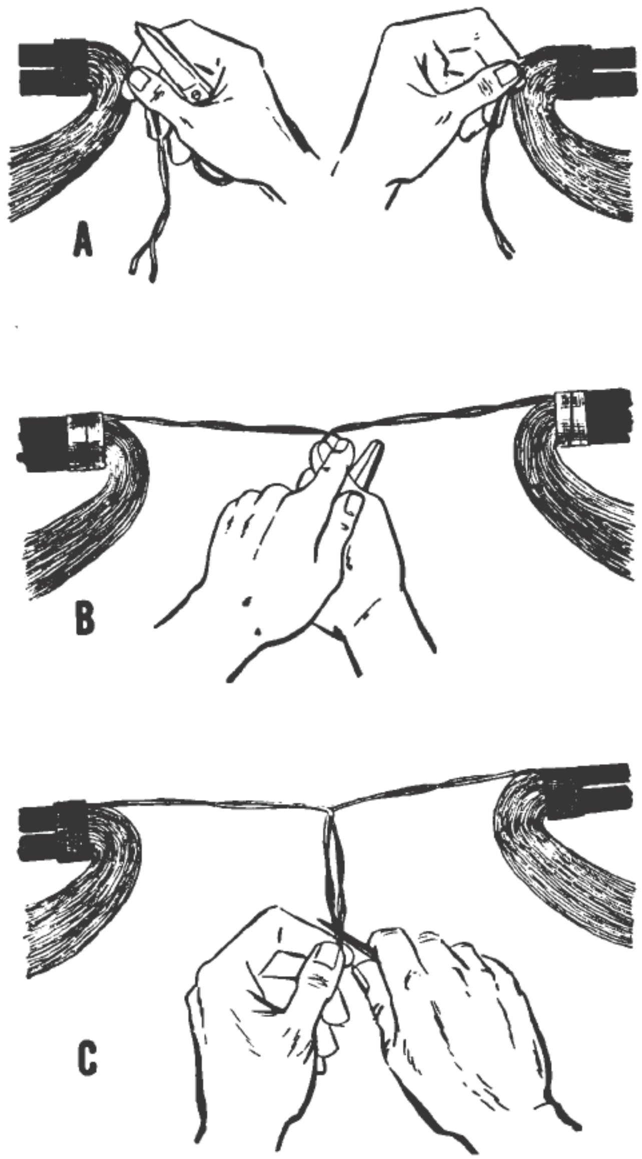


Figure 9-5.—Joining a pair of wires: A, selecting the wires; B, twisting them together; C, cutting them to length.

Before splicing can be done, the insulation must be stripped from the lengths of wire below the twist. Figure 9-6 illustrates this step. You grasp the wires just below the twist, and pull the insulation off the ends of the wires.

It is best to pull away from the twist, and slightly toward the side upon which you plan to slip the cotton sleeve. This will prevent the ends of the wires from curling.

Your wires are in pairs, so you should put the cotton sleeves on both wires at the same

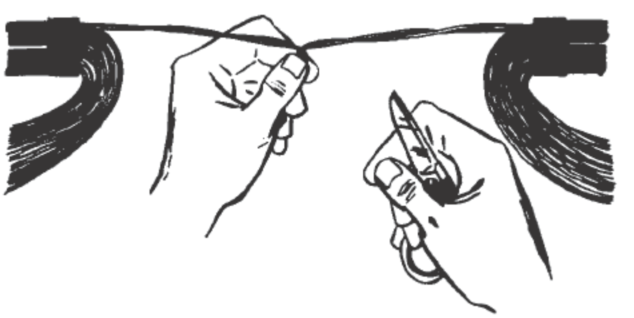


Figure 9-6.–Stripping the insulation from the wires.

time. You can see, in figure 9-7, how both wires of the pair have been fitted with a cotton sleeve.

While you strip off the insulation with your left hand, take a pair of cotton sleeves, waxed and ready for use. Slip them over the wires with a rolling motion, until they have reached a position where they will not interfere with the procedure of twisting the joints.

Bend one wire back, so that it is out of the way as you draw together the second wire, and the wire to which it is to be spliced. At this point, your cables should look like the illustration in figure 9-7.

Draw the wires close together, so that the twist can be made close to the ends of the insulation. You are now ready to begin the "crank handle twist" illustrated in figure 9-8. First roll the left-hand wire over the right-hand one; then bend them at right angles, and twist them together with a cranking motion of your wrist, until the twist is about 1/2 inch long.

Bend or twist the pigtail, and cut off the excess wire. At the same time, slip the cotton sleeve down over the joint, as indicated in figure 9-9. Then begin work on another pair of wires, following the same procedures.

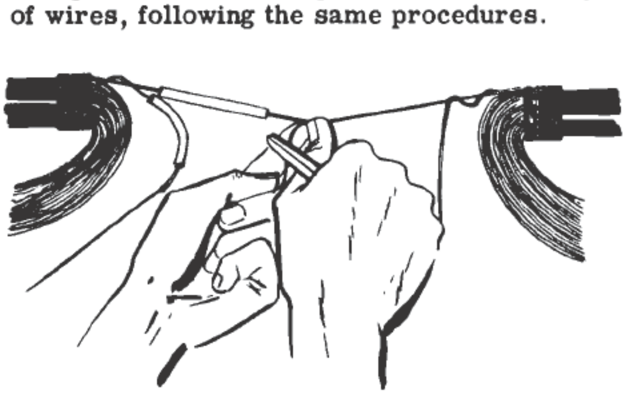


Figure 9-7.–Drawing the wires together for splicing.

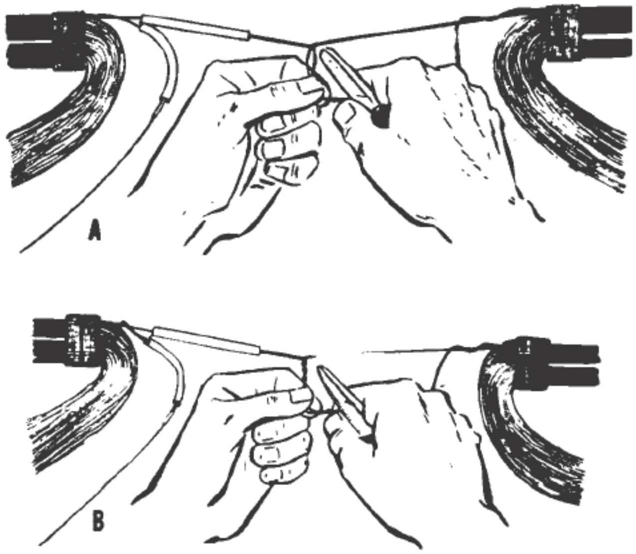


Figure 9-8.–Crank handle twist: A, beginning the twist; B, completing the twist.

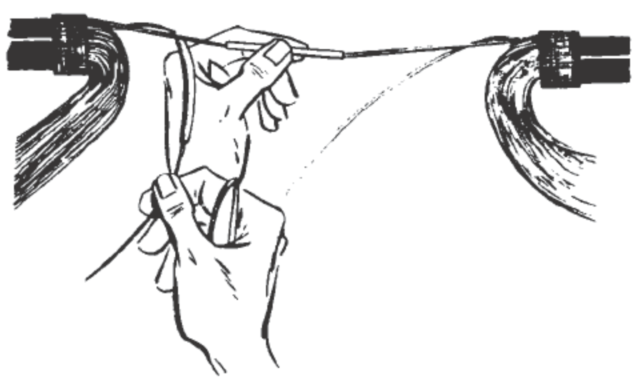


Figure 9-9.–Slipping the cotton sleeve over the joint.

Knowing what wires go together is a very important point in splicing. You are supposed to have a diagram before you attempt any work on cable splicing; or at the least, to have complete and definite instructions as to how to go about the job. This fact has already been stressed, at the beginning of this section.

However, since there is always the possibility, at an advanced base, that you may be called upon to do an emergency job without all the desirable preparation, you will find it very helpful to know something about the arrangement of groups in a cable. Figure 9-10 illustrates the arrangement in a 303-pair cable.

Note the low count at the center, with higher counts about the outer edge.

To determine the count of a 303-pair group cable, stand with your back to the central office (position 4 in fig. 9-10), and facing toward position 5. The white-green group, INNER layer, is counted 1-51; the white-green group, OUTER layer, is counted 52-101. Moving in the clockwise direction from this latter group, you come first to the white-red group 102-152, then to the white-blue group 153-202, to the white-blue group 203-252, and completing the circle, to the white-red group 253-303. When the splicer faces the central office, the direction of counting must be counterclockwise. The illustration in figure 9-10 makes this very clear.

For a cable having 101-pair groups, the individual groups are smaller, but the lowest count is still the white-green group, and the system of counting is the same.

Drying the Splice

On work that has not been previously boiled out, or where splicing has to be done where water may reach the insulation by running along the sheath, the splice MUST be dried out after the wires have been joined. It is advisable always to boil out the finished splice, before wiping the joint. Use a desiccant in the same manner as has already been described; if no desiccant is available, use hot paraffin.

Wiping the Sleeve

When all the pairs of conductors have been spliced, you are ready to slip the lead sleeve over the completed splicing. Take care, in moving the lead sleeve, not to disturb the cotton sleeves; if you move them, the separate wires may come into contact with each other.

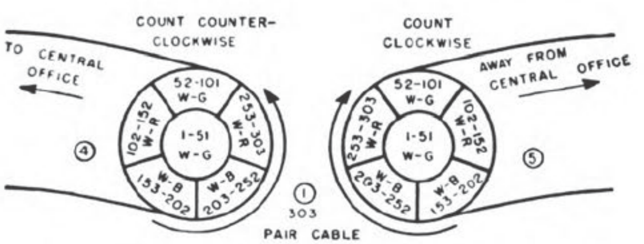


Figure 9-10.–Cable conductor groups, 303-pair cable.

Wrap the spliced area with two layers of boiled-out muslin, and tie in the end of the muslin. Figure 9-11 shows how the cable will look (1) with half of the spliced area wrapped, (2) with the entire splice wrapped, and (3) with the end of the wrapping tied in.

Unless you made your individual splices neatly and compactly, the lead sleeve may not be adequate to cover the splice opening. This will almost certainly be the case if you made all your splices at the same point. Stagger the individual splices, and consequently the cotton sleeves which are pulled over those joints, so that all the joints will not bunch up in one spot.

To make a tight joint, you must beat in the ends of the lead sleeve before wiping the joint. Figure 9-12 shows a lead sleeve beaten in around a spliced cable. The angle, or width of the bevel, depends upon the diameter of the sleeve.

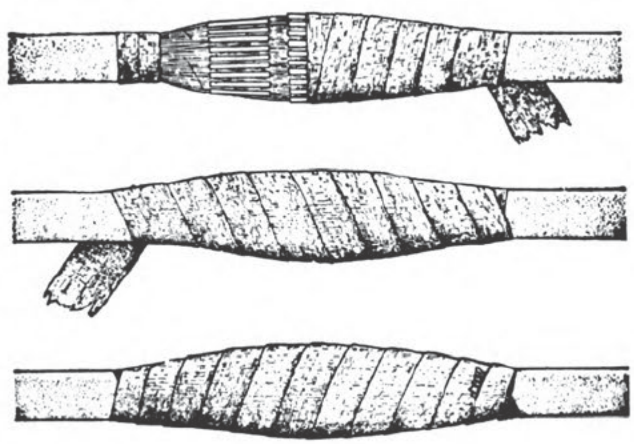


Figure 9-11.–Wrapping the splice.

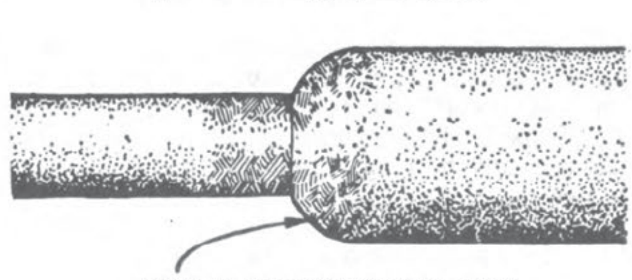


Figure 9-12.–Lead sleeve beat in around the cable.

Revolve the sleeve with one hand, and with a cable dresser tap the end of the sleeve to center it around the cable. Use a lead file; work with quick, sharp strokes, and be careful not to strike the cable sheath. The beat-in portion should be evenly distributed over the surface, so that there is no furrowing.

The final tightening is best done with a riveting hammer. You then apply the pasters. These are strips of brown paper, gummed on one side; they come in rolls which are approximately two inches in width.

At this point, your PREPARATIONS for wiping the joint are completed. The actual wiping process consists of tinning, heating, rough forming, and wiping; the joint is then allowed to cool, is inspected for defects, and the pasters are removed. This series of steps is fully described in the following paragraphs.

Tinning

For tinning, the wiping metal must be of the right composition. It should be approximately 40 percent tin and 60 percent lead. Some splicers prefer slightly more than 60 percent lead, so they add a small amount of pure lead to the 60-40 percent mixture furnished by the manufacturer. A wiped joint that tends to run at the bottom when it is hot indicates a high tin content, and the addition of a small amount of lead will usually remedy this situation. If, on the other hand, the percentage of lead is too high, the joint may wipe easily, but will present a chalky appearance and may be porous. This condition can be corrected by adding 50-50 solder to the wiping metal.

The wiping metal should be used at a temperature of 670 F. Check the temperature with a thermometer. If no thermometer is available, you can check the temperature by folding a piece of dry paper and plunging the end into the hot metal and removing it immediately. If the paper is scorched to a point where it is about ready to ignite, then the metal is ready to use.

Before starting to wipe one end of the sleeve, tack the opposite end by pouring a few drops of solder on it. Tacking means to drop enough molten solder at that end to hold the sleeve steady when the solder cools and hardens.

When you pour the solder, first splash it onto the pasters, at the same time moving the catch cloth back and forth under the joint. (At the start of the operation, do not pour solder directly on the cable sheath or sleeve as it might burn through and damage the conductors.) Continue making a circular motion with the ladle, splashing solder on the pasters and joint, until the entire surface to be wiped is well tinned and no dark spots appear on the sheath or sleeve.

During the tinning operation, do not attempt to bring the solder in the catch cloth up on the sides or top of the wipe. To do so would probably result in a torn cloth, since sharp points form on the chilled metal. The purpose of the catch cloth during tinning is to ensure that the bottom of the joint is tinned and that the solder does not form a hard lump on the bottom of the wipe. This explains why the cloth is moved back and forth. Many men, before they gain experience, tend to hold the catch cloth too close to the cable and sleeve. It should be held at a distance of at least 1/2 inch, to prevent solder from freezing on the bottom.

Heating

The next step is to heat the joint. If the sheath and sleeve are not heated to the proper temperature (approximately that of the wiping solder), you will find it impossible to turn out well-finished wipes. To heat the joint, continue to pour metal onto the joint until it runs freely from the joint. During the pour, bring the metal in the catch cloth up to the top of the splice from both sides and then work it into the ladle. Figure 9-13 illustrates the method of wiping

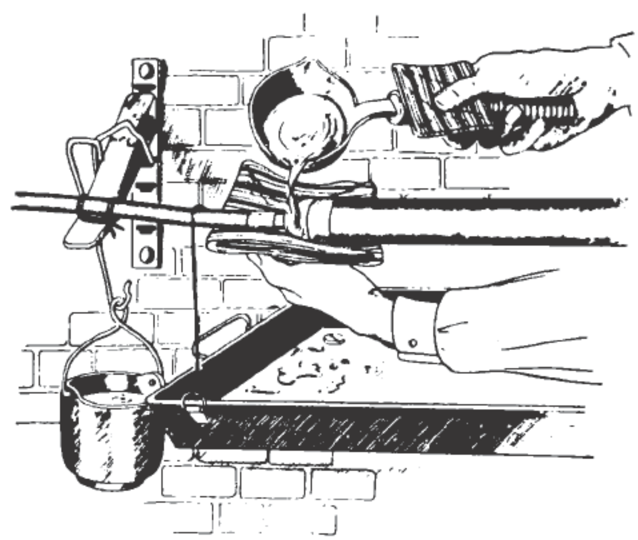


Figure 9-13.—Using a catch cloth to apply solder.

a joint with hot solder and a finishing or catch cloth. If the metal is chilled, it should be returned to the solder pot and a fresh ladleful taken. If the metal is still reasonably hot, some of it can be restored to the pot, while that in the ladle is supplemented by fresh solder from the pot.

The addition of stearine to a joint during the heating process helps to make the metal handle better. A poorly heated joint will cause small mounds of chilled metal to appear at the paster edges. Continue heating until these mounds are no longer present. Protect the wipe with the catch cloth while the ladle is being refilled so that the heat will be maintained.

Rough Forming

When it is apparent that the joint is properly heated, it is time to begin the rough forming. You will learn from practice and experience when the mass of solder has reached the right stage for rough forming. At this stage, the mass is pasty but still quite fluid, and the tin content of the solder tends to run toward the bottom of the joint. During rough forming, place the ladle in the solder pot or drip pan. Manipulate the mass and bring the excess metal to the top of the joint. The process of forming consists of a rapid packing motion by means of the catch pad and a finishing cloth. At the same time, the metal around the joint is shaped or built up by the action of the cloths. This packing should not be continued for too long, or the chilling of the metal will make it impossible to finish or wipe the joint successfully.

Wiping

Use the fewest possible motions in wiping the joint. Three motions are considered the ideal number. The closer you approach this minimum, the better your wipes will be. Repeated wipes in finishing a joint result in a job that is rough and chalky in appearance. Such a joint is commonly referred to as a cold joint, because it looks as though it had been wiped with cold metal.

When preparing to finish the joint, hold the finishing cloth at the top edge between the thumb and forefinger of each hand, with the middle fingers alongside the edges to exert pressure. Bring the first wipe from the bottom to the top of the joint on the side away from you. Perform the second wipe in the same manner without altering the position of your hands. This enables you to see the condition of the bottom of the joint during the final wipe and allows you to maintain equal pressure on both sides of the joint while completing the wipe. The third wipe should be a light stroke, made in a direction parallel with sleeve and cable.

Take care not to move your feet when you are finishing a wipe. This is an important precaution when you are wiping aerial cable, because the slightest movement on the splicing platform may result in a cracked splice.

Before you inspect the finished joint for possible defects, allow it to cool. Movement of the joint before the wipes have cooled can cause cracks. If the cooled joint is satisfactory, you can remove the pasters.

The finished joint should have a good appearance, if it has been properly made. Never try to improve its appearance by applying corrective measures, such as smoothing with file or emery cloth, trimming with knife or shears, or touching up defective spots with a soldering iron. If the joint is not satisfactory, the only thing to do is to rewipe the splice; otherwise, the joint will break down under operating conditions.

Use of Split Sleeves

Split sleeves are used to permanently close an opening in an existing cable. Sometimes this opening will be the result of the removal of a lead sleeve where a splice had previously been made. Where the latter is the case, the split sleeve that you use to replace the original sleeve must be longer than the original. In this way, you ensure that the wiped joints which you will make will not come at the same point on the cable as the old wipes.

The new sleeve, since it cannot be slipped over an end of a cable, must be split, and then later seamed. Whether the split sleeve covers an opening where a previous splice was made, or an opening where there was no previous splice, the methods of splitting it and seaming it will be the same.

Mark the part to be split by scoring with a screwdriver, a shave hook, or splicing scissors. You can ensure a straight cut by laying the sleeve parallel to a straightedge when you mark

it. The split may be made with a piano-wire sleeve splitter, or with a cable saw.

To split the sleeve with piano wire, use a piece of 20-gage steel wire; drop it through the sleeve, and then pull steadily on both ends. Make sure that the wire cuts along the groove marked on the sleeve. Wooden handles attached to the wire make the cutting operation easier. With a cable saw, you must be very careful not to damage the inside wall of the sleeve, opposite to where you are making the cut. Any feathering inside the cut must be removed with a shave hook.

After you have split the sleeve, you must open it enough so that you can easily slip it over the cable. Using a screwdriver or a shave hook is likely to damage the sleeve wall. If you do not have a regular sleeve spreader, use a small wooden drift pin that is long enough to protrude an equal distance from each end of the sleeve. With the pin in the horizontal position, and the split of the sleeve on top, tap the protruding ends of the pin against a stationary object until the sleeve opens. Work from alternate ends, until you have made a gap that is uniform and of the desired distance.

After the sleeve has been placed on the cable, close it with marline, or with muslin ties. If the ends fail to meet evenly, grasp each end of the sleeve, and twist in opposite directions. This method will not work, however, on large sleeves. You will have to run two pieces on either side of the split, and close to it; then twist the ends, with a bar of solder, until they meet evenly.

With the sleeve on the cable, and both ends even, you are ready to seam up the split. For convenience, have the split uppermost. Tack the seam in at least four places; smear the lead, and spread it by a drawing motion. Then use a shave hook, as shown in figure 9-14, to perform the same smearing operation between the tacked points, so that the full length of the seam will be closed.

If you tack the sleeve too lightly, it may separate or buckle during the beating-in procedure. Also, if you allow solder to penetrate from the seam into the sleeve, the slight movement of the sleeve during the beating in process can cause the chilled solder to cut through the muslin, and damage the conductors.

To avoid these difficulties, some men beat in the ends of the sleeves before splitting the sleeve. When this method is followed, a slight

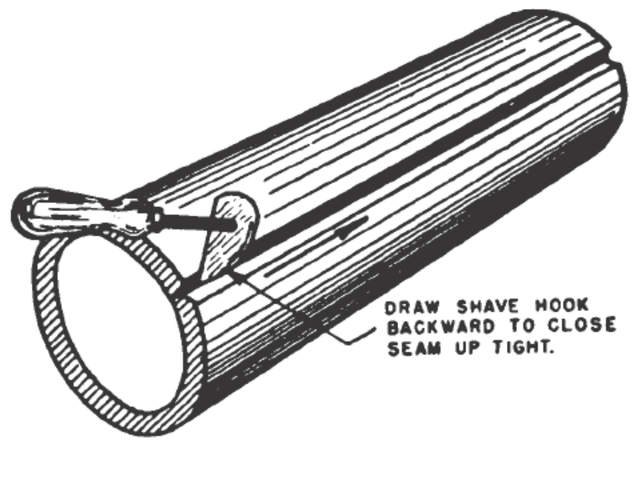


Figure 9-14.—Running the seam of a split sleeve.

tack at each end will hold the sleeve in place during the closing of the seam.

The tinning and wiping procedures are the same as those already described in the section on the lead sleeve.

In closing a split sleeve, keep in mind that this seam will probably decide the practical value of the job done in closing the cable opening. No matter how sound a wiped joint may be, it will be inadequate if the seam is unsound. The tightness of the seam, as you will find when you are actually doing these work processes, depends only partly upon the soldering copper, and chiefly upon the preparation of the sleeve.

RESIN PRESSURE SPLICING

The resin pressure method of splicing is a procedure adapted from the use of resin material for insulating and protecting condensers, transformers, and motor coils. This resin can be used on either power or communications cables. When it is injected under pressure, it permits the perfect saturation of the splice, regardless of shape or position. It is applicable, therefore, to straight or branched connections, or to terminals.

Splicing kits are available for specific types of splices—for example, in straight (line) and bridge (Y) splices; indoor-outdoor cable terminations; and Y or tap splices in lighting systems, traffic signal systems, and so on. These various kits include in one package all the materials necessary for the particular type of job.

All types of resin pressure splices, whether for power or communication cable, and regardless of size or configuration, should be made according to the following procedures:

1. Scrape the outer sheath clean, so that there can be maximum adhesion of the resin, when it is applied. This point is of the utmost importance.

2. Use a compression or solder sleeve connection, preferably one without sharp corners, or other electrical stress concentration points. One type of compression sleeve connection is shown in figure 9-15.

Courtesy of Minnesota Mining and Manufacturing Co.

Figure 9-15.—Compression sleeve connection.

3. Wrap the spacer about the splice area, to the desired thickness of the resin insulation. There is a knack in applying the spacer so as to avoid uphill or downhill winding; the first serving of the spacer should extend full length, with each successive serving a bit shorter.

4. Locate the injection fitting near one end of the splice. The check value action in this fitting serves to retain pressure in the splice, after the resin has been injected and the pressure gun removed.

5. Apply the tape envelope. Start the first strip on one side of the injection fitting, and apply a half-lap wrapping that extends beyond the end of the spacer. Stretch the tape to conform to the spacer build-up; gaps or wrinkles will allow the resin to leak, when it has been injected. Start the second strip of tape on the opposite side of the injection fitting, and proceed as before.

6. Apply a restricting tape envelope. This must be of nonstretching tape, and must be firmly wrapped over the tape envelope. Its purpose is to prevent any stretching of the tape envelope when the resin saturation is made. Half-lap this nonstretching tape the length of the spacer, then reverse direction, and half-lap back to the starting point.

7. Make a very small hole, at the end of the restricting tape farthest from the injection fitting. During resin saturation, this hole will vent air; and it will indicate when the splice is fully saturated through the main portion, by showing a small drop of resin. When this droplet appears, you should make a second small vent through the restricting tape, at the end nearest the injection fitting. When a droplet appears at the second vent hole, you can withdraw the pressure gun.

8. Prepare the resin preparation as soon as the plastic tape and the restricting tape have been applied, and the first vent perforation has been made. There should be no delay between the preparation of the resin, and its application, inasmuch as the "working life" of the resin is limited. Remove the paper liner from the spout of the resin pack, and insert the spout into the nozzle of the gun. If the splice is a large one, it may be necessary to use two or more resin packs.

This special technique for resin pressure splicing is of recent development, and may not be in use at your base. However, in the event that it later becomes a widely employed method of splicing cable, you should have some basic knowledge of how it is to be applied.

SPLICING SILK AND COTTON INSULATED CABLE

Paper ribbon or paper pulp insulation has certain disadvantages that make it a poor choice for use on cables to be connected to distributing frames, terminal strips, and other interior terminal points. This is because the paper wrap insulation is not strong enough to stand the amount of handling necessary. In making the core into a form which is fanned out and laced, the paper would unroll, since it is not baked on. Further, paper insulation deteriorates when exposed to air, and its resistance is rapidly lowered when the cable is exposed to moisture.

It is customary, therefore, to have incoming paper-insulated cable spliced onto short lengths of lead-covered textile-insulated cables, called cable heads. These latter are used to make the direct connection with central office distributing frames and terminal strips.

Prepare silk and cotton insulated cable for splicing by boiling out with beeswax, or with a special petroleum wax. Do not use paraffin, because it discolors the textile insulation, and makes it very difficult for the operator to separate conductors for fanning, forming, and splicing. On the other hand, do not use beeswax on the paper-wrapped insulation, since it will make the paper brittle, and may cause breakage.

Start pouring the wax a few inches back on the sheath, and gradually advance toward the exposed conductors. To start at the conductors would defeat the purpose of the boiling out, since any moisture under the sheath would be forced farther back.

The same standard splice openings, number of cotton sleeve banks, and splicing procedures apply to textile-insulated exchange cables as apply to paper-insulated exchange cables.

To mark the point for removal of textile insulation, use the same procedure as used for paper-insulated cables. Cut off the conductors 4 1/2 inches from the end and use long-nosed pliers to crush the silk- and cotton-insulation at the marked point. Don't apply too much pressure, as this will flatten the conductor, and may cause it to break after it is spliced. After the insulation has been crushed, it can be removed by decreasing the pressure on the pliers and pulling toward the end in a straight line. The insulation can also be pulled from the conductors with the fingers. Never use the back of the splicing scissors to remove the insulation; such a method might break the relatively brittle tinned-copper conductors in textile-insulated cables.

Some textile-insulated cables have enameled conductors. This enamel must be thoroughly removed before the wires can be spliced. One way to remove it is by lightly scraping the conductor between the jaws of long-nosed pilers. You must be extremely careful not to nick or flatten the wire. A good tool for scraping enamel is the wire scraper, which consists of a steel spring 3/4 inch wide, bent in the form of a U with the ends turned and sharpened. As you gain experience with this tool, you will find it effective for removing silk, cotton, or plastic insulation.

To twist the conductors, use the same 3 to 5 turn twist (3 or 5 loose, 3 or 5 tight) as you would employ in splicing paper-insulated cable. After the splice is completed, boil out with hot paraffin, or dry with a desiccant, just as you would a paper-insulated splice.

SPLICING BURIED CABLE

Buried service cable is generally used for substation underground service connections. The cables consist of one-pair or two-pair lead-covered rubber-insulated cable to which protective covering of paper, jute, or steel tape has been added.

In some cases, telephone cables may have been installed in the same trench as power or lighting cables. (Telephone cables should be at least six inches from the power cables.) You must check on the possible presence of these other cables before you make any sheath openings.

Splices should be made at manholes, handholds, pedestals, or buried splice points. If you must work at the latter positions, widen the trench so as to make your splicing work easier to perform.

Plan the splice layout carefully, to avoid unnecessary removal of protective covering. Remove any dirt that adheres to the covering before you slide the lead sleeve over the cable. When the splicing is completed, paint the lead sleeve, the wiped joint, and the exposed cable sheath with a protective compound, and wrap the whole section in three layers of black friction tape or muslin.

CABLE REPAIR

Making minor repairs because of ring cuts, sheath breaks, lightning burns, bullet holes, and other damage to small aerial cables may be part of your job. Such damage can be repaired by the carbon electrode welding method or with an acetylene torch. The carbon electrode method is easier to use if damage extends through the sheath and moisture has reached the conductor insulation. The acetylene torch method is preferable if the damage does not extend through the sheath.

Water-soaked paper insulation usually causes the pairs to become shorted. Shorted pairs are frequently the first indication that a sheath has been damaged so much that moisture can enter.

Use the following steps for repairs of this nature:

1. Open and spread the sheath.
2. Dry out the insulation with desiccant.
3. Repair charred or corroded insulation.
4. Test the cable pairs before preparing to close the sheath.
5. Close the sheath.
6. Solder the seam and restore cable hangers to appropriate spacings.

Opening the Sheath

After the fault has been located, and the ladder or splicing platform has been put in position, you should proceed to open the sheath in the following manner:

1. Straighten the cable if necessary. You can lessen cable tension by placing grade clamps to hold the cable as desired, until the repair operation has been completed. If the cable is not extremely taut, this will not be necessary.
2. With a wire brush, brighten the lead sheath in the section to be split.
3. Rub stearine along the cable where the lengthwise cut is to be made. As the cut is made, continue to lubricate with stearine.
4. Adjust the small blade of the cable stripper so that it will penetrate 1/32 to 1/16 inch. Make the starting cuts with the small end of the blade. Rout out the small shavings of lead. Each cut will make the succeeding cut easier. After a definite line of cut has been established, turn the tool over, and use the large end of the blade to bevel the cut. Do not cut all the way through the sheath with the large end. Just before the blade is about to break through the sheath, reverse the tool and complete the cut with the small end.
5. After you have cut through the sheath, open it with cable pliers. Grasp the handles of the cable pliers firmly and open the incision on one side. Placing the sharp jaw in the cut, work the tongs sideways, exerting a small downward pressure at the same time. Bend the sheath cautiously, so as not to put too much stress on it and perhaps deform it. When one side of the cable sheath is bent back, repeat the process on the other side.

After the cable sheath is open, push out the paper-insulated cable by inserting a wooden wedge between the sheath and the wires, in the manner shown in figure 9-16. Insert enough wedges between the core and the sheath so that you have room to work. Remove the paper wrapping to expose the wires so that they can be dried out by using a desiccant or by boiling out with paraffin.

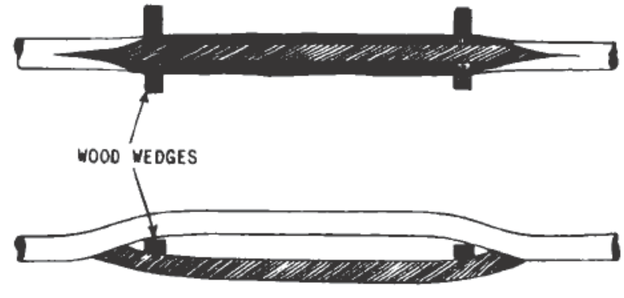


Figure 9-16.—Wedges inserted in a cable, to permit drying out.

Repairing Insulation

The cut must be long enough so that joints in the spliced wires can be properly staggered along the length of the opened cable. Use paper tape to avoid piecing out wires on which the insulation has become blackened because of electrolytic action. To apply the tape, pull the pair out and cut a piece of tape long enough to extend at least 1/2 inch beyond the corroded portion. Press it down with your fingers. Trim off the excess tape with your scissors. In hot weather take care that perspiration from your hands does not dampen the insulation.

After all damaged wires are repaired, push cotton tape under the edges of the sheath with a butting tool. Wrap the core with 1-inch tape which has previously been boiled out in paraffin, and then push the core back into the sheath. Test the cable pairs to be sure that all trouble is cleared.

Before closing the cut in the sheath, cut a piece of press board about 5/16 inch wide and equal to the length of the opening. Lubricate the top of the press board generously with stearine so that the edges of the cut will slide back into their original position more readily. Use tongs to press the lead sheath back into its original position. It is not necessary to close the cut entirely, but if the cut is left partly open, the press board should cover the core so that it will not be damaged if the electric welding process is used in closing the cable.

In closing the sheath, you should work the cable into shape gradually. First squeeze it together with your hands; then shape it into its original shape by applying pressure with tongs kept lubricated with stearine. Do not roll the tongs over the sheath, as this will produce depressions around the circumference. Take care, also, not to apply pressure directly over the cut until the cable is well shaped; otherwise, you will probably flatten out the cable.

After the sheath has been closed over the core so that the edges of the cut are from 1/8 to 1/4 inch apart, use the scoring tool and a

wire brush to clean the sheath. Apply pasters along the edges and ends of the cut, to fix the width and length of the closing joint. Place these pasters about 1/16 to 1/8 inch from the edge of the cut. Use a halfround bastard file at each end of the cut to form a depression into which solder can be flowed to seal any fine cracks caused by bending the sheath back. After the pasters are in place, apply stearine to the portion to be soldered.

Stearine core solder should be fused to the sheath by holding the end of the solder in contact with the sheath, and touching the solder with the edge of the beveled end of the electrode. In this manner coat the entire area to be soldered. Use only the minimum amount of solder. Heat and manipulate the solder deposited on the sheath with the beveled surface of the electrode, to tin the entire area of the patch. To ensure the tinning of the entire surface of the deep narrow cut, turn the electrode so the edge of the beveled surface can be moved along inside the cut.

Light contact and a circular motion of the electrode on the solder will aid in raising the temperature of the solder so that the tinning can be accomplished to best advantage. Additional solder should be flowed into the cut to fill it to the top. Move the electrode over the patch to remove air bubbles and flux, and to give the repair a reasonably smooth appearance. The completed patch should project very little above the surface of the sheath. After completing the welding, remove the pasters and use a coarse file to smooth off any rough spots in the seam. Smooth off the sheath with a wire brush. Leave the cable as sound and as free from marks or creases as possible.

Repairing Cracks with an Acetylene Torch

Small defects, as mentioned before, such as ring cuts and cracks may be repaired with an acetylene torch, provided they do not extend through the sheath. It is best not to use the torch for cuts that penetrate the full depth of the sheath, since it would be easy to damage the insulation by the heat from the torch.

Acetylene is a highly flammable gas, and it is explosive in confined spaces. Never use the acetylene torch for making repairs in manholes, or in any enclosed space. If you are working on aerial cable, however, you will find the torch an excellent means for repairing any cracks that may occur while the cable is being worked.

Before you use an acetylene torch, make sure that you fully understand its operation, and the safety precautions which should be observed. Operating instructions that come with the torch equipment will give you the necessary information. You will find this type of torch fully described in *Steelworker* 3 & 2, NavPers 10653-C, and also in *Shipfitter*-P 3 & 2, NavPers 10592-B.

Never keep the torch lighted except when making repairs. If spots to be repaired are close together, it is safe to make repairs without turning off the gas at the cylinder outlet; but if you change position, or have to pass a pole, be sure to extinguish the torch by turning the needle valve.

Stearine core solder should be used to make sheath repairs with the acetylene torch. Thoroughly clean the area around the defect with a brushing motion. Apply the flame to the cleaned area, being careful not to concentrate the flame in one spot. Don't allow the blue cone in the flame to come into contact with the sheath. Apply solder over the area of the defect, using sufficient heat to tin the area thoroughly. Build up enough solder to fill the cut or depression. Use a small finishing cloth to pack the solder into the defect and smooth off the patch so that it is only slightly above the level of the adjacent sheath. The repairs should extend from 1/4 to 1/2 inch beyond the defect.

TOOLS AND MATERIALS

The tools and equipment that are required for splicing cable are roughly as follows: cable dresser, cable saw, chipping knife, drift pins, files, pliers, shave hook, scissors, and tongs. You must also have a furnace or firepot for general heating and melting purposes, a paraffin dipper, and a solder ladle.

Among the materials that you will use are: tapes, muslin, pasters, beeswax, paraffin, stearine, solder, wiping compound, and desiccants.

Most of these have been mentioned already in this chapter, and probably require no further explanation. Some of the hand tools are described in the basic training course, *Basic Hand Tool Skills*, NavPers 10085.

Figure 9-17 shows the tools which you will commonly use; and the following paragraphs of

Figure 9-17.–Splicing tools and equipment.

additional information should enable you to recognize them, and to know when and how to use them.

The HACKSAW comes in handy whenever a cutting job is required on the cable. The CABLE KNIFE is used to cut away insulation and fillers after the lead sheath has been removed. The SHAVE HOOK is a scraping tool, used to clean and prepare the lead sheath surface for soldering or wiping. Measurements are made with the 6-foot FOLDING RULE. The TINNER'S HAMMER is used for dressing and shaping.

Cutting of the conductors is accomplished with the 8-inch CUTTING PLIERS. The CHIPPING KNIFE (also called hacking knife) is used to ring and slit the lead sheath to facilitate its removal. Although the SCREWDRIVER is not normally used as a prying tool, it can be adapted to this use on the soft lead sheath without damage.

The CATCH CLOTH and FINISHING CLOTH are pads of herringbone bed ticking used to catch and shape the solder during the wiping process. The SOLDER POT and LADLE serve as container and dispenser, respectively, of the liquid wiping solder.

The heating equipment consists of the GAS FURNACE for heating the solder, the GAS TORCH for local application of heat, and the GAS TANK for storage of the butane gas used by the torch and furnace. A regulator valve reduces the high gas pressure in the tank to a safe, usable pressure at the furnace or torch. If this type of heating equipment is not available, a blow torch can be substituted for the gas torch, and a gasoline furnace for the gas furnace.

Figure 9-18 affords an additional illustration of equipment that you will use in a splicing job.

The electrician's scissors shown in the figure represents the pair that are kept in the leather pouch fastened to your belt.

The braid stripper is equipped with a guard that holds the wire in correct position for cutting. The openings in the handle are to accommodate the various sizes of hexagon nuts used on connectors.

The cable splicer's thermometer is used for determining the temperature of the wiping solder. Most cablemen find out by experience what temperature is best for the various sizes of cable. The man in charge of the job will sometimes slip the ring out of the head of the thermometer, remove the glass, and mark on the dial the point that he considers the optimum temperature. This mark will be a big help to the crewman that has the job of heating the solder.

The paraffin trough shown can be used to permit paraffin to flow into the pot; or it can be used to catch wiping solder.

The lead sleeve used to cover the spliced area has been fully described earlier in the chapter. Note how the ends have been cleaned, and covered with stearine.

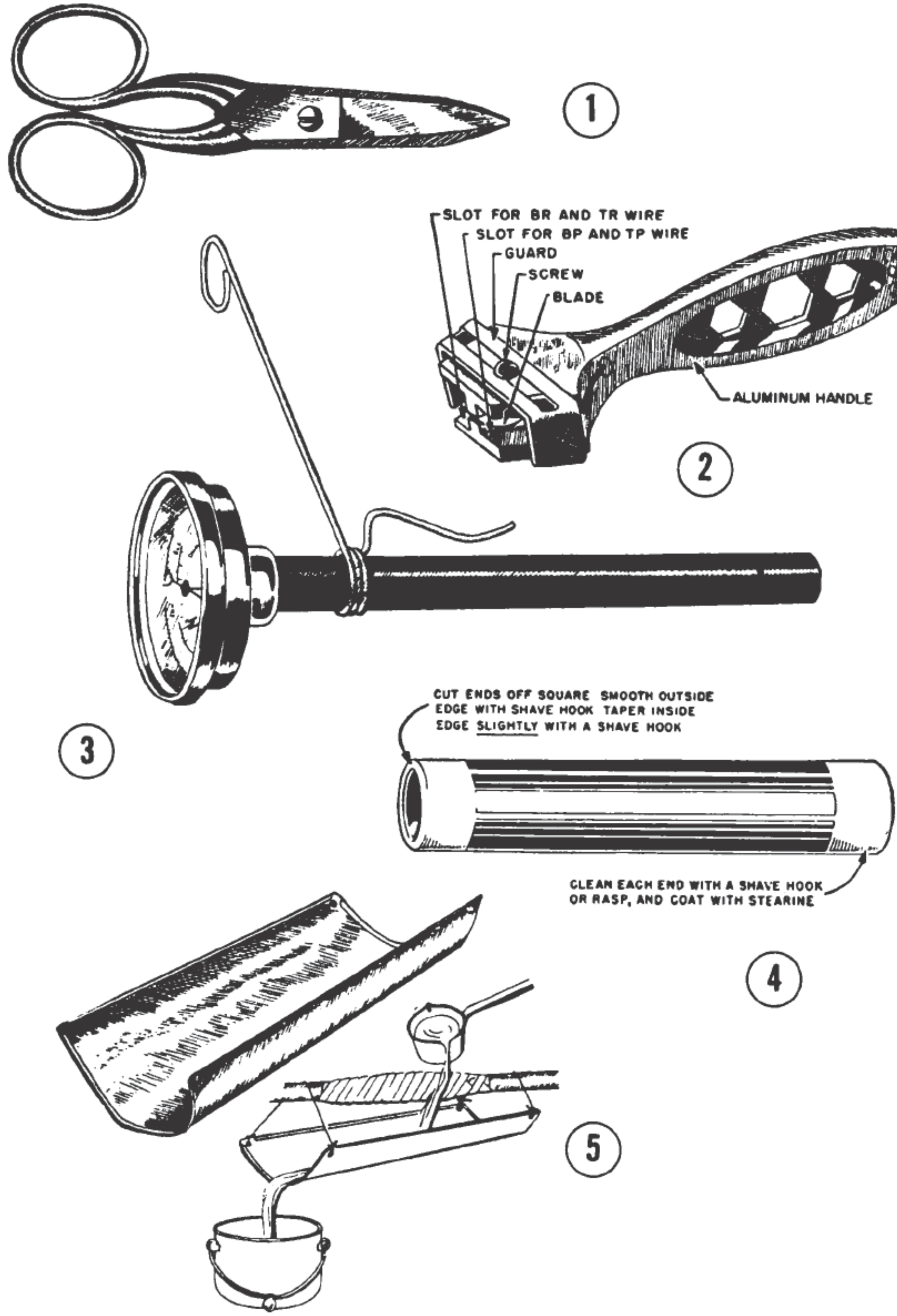


Figure 9-18.—Cable splicing equipment.

QUIZ

1. The wire-armored type of cable used in marshy and swampy areas is known as
   (a) buried cable
   (b) conduit-covered cable
   (c) submarine cable
   (d) composite cable

2. What is meant by the term "composite cable"?

3. What are the 3 commonly used types of telephone cable splicing?

4. What is the reason for cleaning the sheath of both cables for a distance of several inches, in preparation for splicing?

5. Why should the edges where the sheath has been broken off be smoothed?

6. What is the purpose of a lead sleeve?

7. Name the 3 major factors that determine size of a lead sleeve.

8. What is the major purpose of boiling out insulation in an area where splicing is to be done?

9. When hot paraffin is used to boil out insulation, it should be applied at a temperature not higher than
   (a) 325 F
   (b) 350 F
   (c) 375 F
   (d) 400 F

10. How does a desiccant act to dry out the moisture in cable insulation?

11. Aerial cable that is to be spliced can be held in position by
    (a) applying a split sleeve to the cable
    (b) using slack pullers
    (c) using cable rings
    (d) lashing the cable

12. Unless you stagger the individual joints in each pair of wires, what may happen?

13. When you are beating in (or beveling) a lead sleeve around a spliced cable, the width of the bevel will depend upon the
    (a) size of the cable
    (b) number of spliced conductors
    (c) diameter of the sleeve
    (d) length of the splice opening

14. The recommended composition for a wiping metal is
    (a) 40 percent tin, 60 percent lead
    (b) 50 percent tin, 50 percent lead
    (c) 60 percent tin, 40 percent lead
    (d) none of the above

15. Why is the catch cloth moved back and forth during a tinning operation, instead of being wrapped around the wipe?

16. To ensure a good wipe, the sheath and sleeve should be heated to what temperature?

17. The best wipes are produced when the wiping motions are
    (a) repeated as often as possible
    (b) held to a minimum
    (c) made with a slow, prolonged, packing motion
    (d) made until the joint has a chalky appearance

18. What is the disadvantage of using a cable saw to split a lead sleeve?

19. Paper wrap insulation should not be used on cables connected to distributing frames, for which of the following reasons?
    (a) It is not strong enough for fanning out and lacing.
    (b) It deteriorates when exposed to air.
    (c) It loses resistance in damp atmosphere.
    (d) All of the above.

20. What are cable heads? What purpose do they serve?

21. Why is beeswax, rather than paraffin, used for boiling out silk and cotton insulated cable?

22. In making cable repairs for minor cuts and breaks, when should you use a carbon electrode welding electrode? When should you use an acetylene torch?

23. When you find that the insulation on wires has become blackened by electrolytic action, the corroded portion can probably be repaired by applying
    (a) a cotton sleeve
    (b) a coating of stearine
    (c) soldering flux
    (d) paper tape

24. Why is the acetylene torch safer for work on aerial cable than for work in manholes?

CHAPTER 10

SHOP WORK

The electrical repair shop is the general headquarters at an advanced base for all repair and overhaul of electrical equipment. In many cases, defective equipment will be sent to the shop, and worked upon there; but you may also be sent out to substations or shops, to work on motors or generators that are giving trouble.

It would be impossible to give, in one chapter, all the detailed information that you would need to repair all designs of generators and motors. The data given here, however, will enable you to handle most of the equipment at a base. Then, too, you will be able to get advice and help from higher-rated men.

TOOLS AND EQUIPMENT

The amount and the type of equipment in a repair shop vary from base to base, but there will be certain basic equipment which you must have in order to make repairs to motors and generators. There is usually an armature stand and a coil winder, to take care of the rewinding of armatures and field coils. There should be a dipping tank, and an electric oven for drying out varnish on armatures and stators that have been dipped, and also for drying out insulation.

There should be a test switchboard, to be used for testing voltage, current, and resistance of a-c and d-c machines. A portable generator that can be used as a source of voltage should also be available. The various types of meters described in chapter 5 of this training course will probably be part of your shop equipment.

Bench lathes, drills, grinders, tension racks, taping machines, and pipe threading machines will be needed in various types of repair work. In addition, there will be the usual small tools common to any shop: rules and calipers; hammers and mallets; hacksaws; files, punches, shears, pliers, and clamps; taps and dies; and vises.

Figure 10-1 shows a bench lathe, with an armature mounted in it. Figure 10-2 illustrates a pipe and bolt threading machine. The hand tools are those described in *Basic Hand Tool Skills*, NavPers 10085. Some items of shop equipment have already been described in the preceding chapters of this text; illustrations of other tools and equipment, in actual use, will be found throughout this chapter.

If your shop is a large, well-equipped one, there will probably be a coil winder, similar to the one shown in figure 10-3. You will also be supplied with internal and external growlers, for determining circuit faults. These two devices are illustrated in figures 10-4 and 10-5.

In the repair shop, you will be working under the direction of the shop foreman (either a Construction Electrician First Class, or a Chief Construction Electrician), and you will receive the necessary instructions from him. However, it will be to your advantage to learn as much as possible about these tools, so that you will know the correct tool for the job in hand, and will be able to operate it safely and skillfully.

The components of electrical equipment are delicately balanced. Any rough handling can easily impair them, by throwing them out of balance, or by damaging the insulation. Breaks in the insulation may cause opens, shorts, or grounds.

KNOWLEDGE OF MOTORS AND GENERATORS

Before undertaking any overhaul or repair of electrical equipment, the repairman should know in general how the equipment is put together, and how it is supposed to work. He should be familiar with the information given in the section, Electrical Principles as Applied to Motors, in chapter 2 of this training course, and in the section, Electrical Theory Applied to Generating Equipment, in chapter 6.

The instruction manuals that come with the various pieces of electrical equipment are especially valuable in the repair shop. The suggestions for maintenance and repair contained in those manuals will often be the only

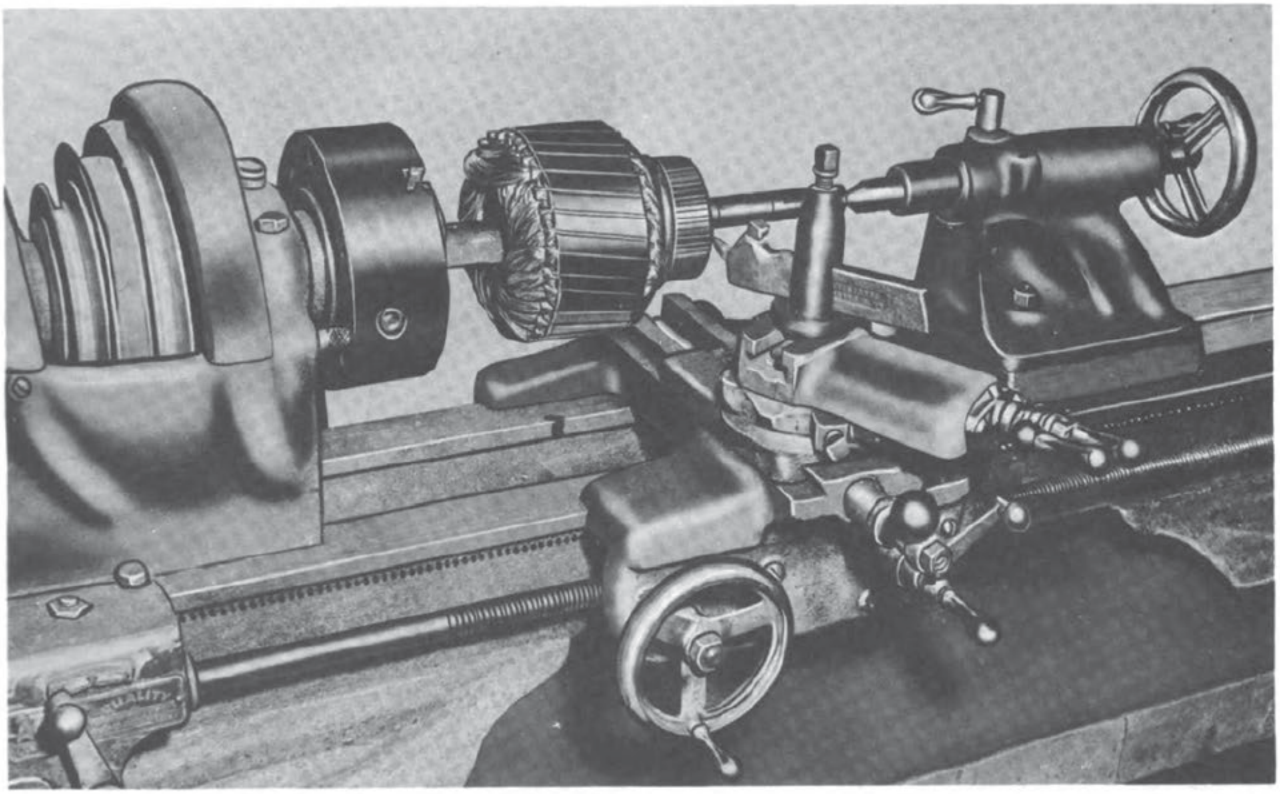


Figure 10-1.—Bench lathe being used in commutator repair.

guide that you will need in restoring the equipment to good operating condition.

The direct current generator that you are likely to encounter at an advanced base is the small generator used as an exciter for the a-c generating plant. Most of the repair work that you will ever be called upon to perform will be in connection with a-c generators and motors.

The components of the a-c generator are: rotor, stator, exciter, frame, and shaft. The rotor, of course, is the rotating part; the stator is the stationary part; the exciter provides the field current for the a-c generator; the frame supports the components, and completes the magnetic circuit of the field; and the shaft is the part upon which the rotor turns.

A single-phase generator is low-powered and self-excited. It is the three-phase generator with which you will usually deal. In most of these machines, there are six armature (or stator) leads, one pair to each phase winding.

These leads are brought out to the terminal box. Connections may be either Y (sometimes called star) or delta. All phase voltages are equal in magnitude; they differ in phase by 120 degrees. You can refresh your knowledge of these generator windings by referring back to figures 2-9 and 2-10.

The generator switchboard consists of generator panels, bus tie panels, and feeder panels. On small switchboards, the various meters, the rheostats, the switches, and so forth, are installed directly on the board.

REPAIRS TO GENERATORS AND MOTORS

Except for the special procedures required in the rewinding of armatures and stators, repair processes are very much the same for generators and motors. The general repairs are discussed in the first part of this section; specific repairs to generators, and the probable cause of various trouble symptoms; are next taken up; and the final part of this section deals with repairs and trouble symptoms for the various types of motors.

Regular inspection, cleaning, and lubricating at the station where the electrical equipment is in use will usually keep this equipment in good service. If the operator watches the performance of new motors and generators until he is

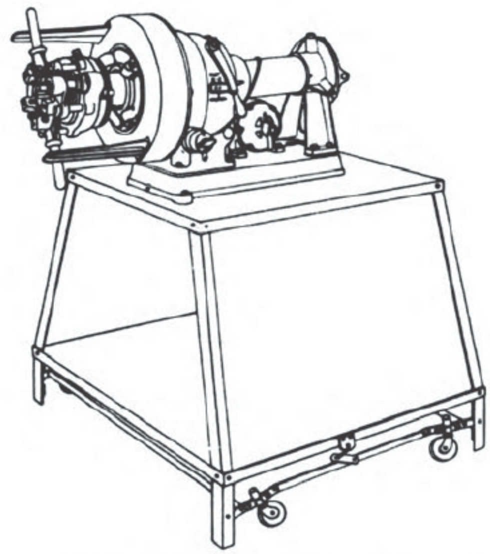
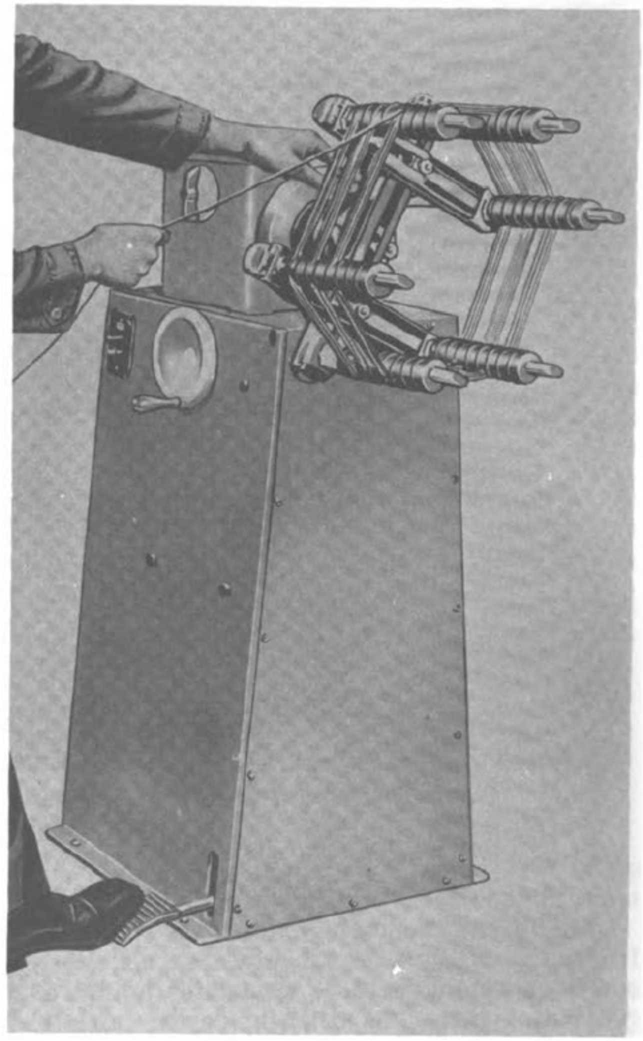


Figure 10-2.—Machine for threading bolts and pipes.



Courtesy of Crown Industrial Products Co.

Figure 10-3.—Coil winder drive and head.

sure that their operation is satisfactory, and if he gives extra care to the inspection and cleaning of old equipment, there will be less burden on the repair shop.

However, there will be cases where the machine operators have failed to follow regular schedules of maintenance, and therefore you will find it advisable to make a preliminary inspection, to determine if neglect rather than mechanical breakdown is causing the trouble. Sometimes the simple procedure of removing foreign matter (iron dust, abrasive particles), of resetting brushes, or of lubricating bearings, will restore the machine to satisfactory operation.

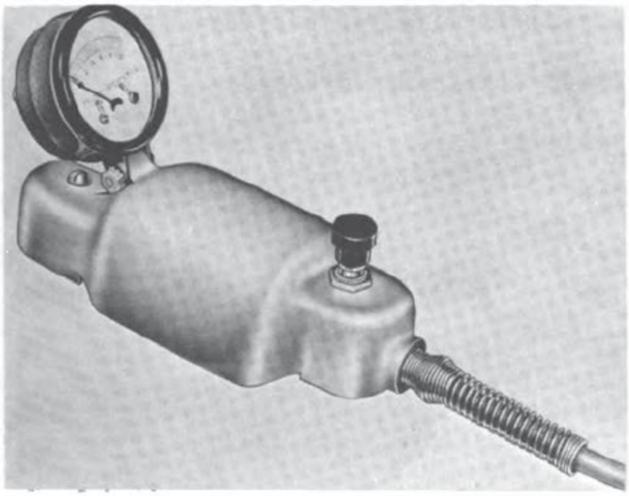
Never be hasty or careless in disassembling a generator or motor. Handle the delicate components with care, so as not to damage them, or to create the need for additional adjustment. Use the proper tools; label the parts as you dismantle them, and store them in an orderly arrangement in a safe place. Note down the necessary information so that you will have no trouble in reassembly.

If you have done a careful job of breaking down a machine into its components, the process of reassembling it should be the reverse order of taking it down.

When you remove end bells, punch-mark the frame and mating end bells as indicated in figure 10-6, using a different mark for each end. Later on, these marks will facilitate reassembly. Remove fastening screws, bolts, and ball-bearing cap plate screws. Use a rawhide or rubber mallet to part the end bells from the frame. The armature or rotor will now rest on the stator.

Protect the windings, if necessary, by inserting thin strips of waxed wood in the gap between rotor and stator. Record the connections of all internal mechanisms and parts.

Clean the end bells with a brush and an approved solvent. Check them for cracks, burrs, nicks, and excessive paint, as well as for dirt.



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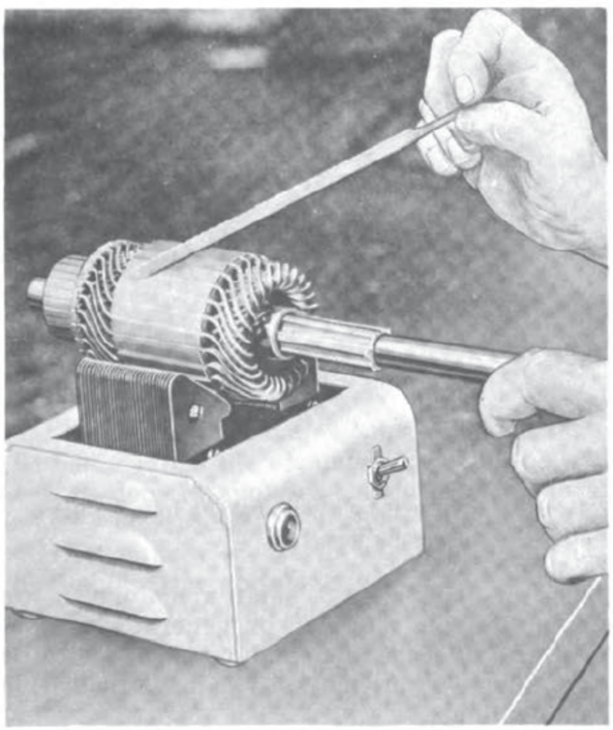


Courtesy of Crown Industrial Products Co.

Figure 10-5.—External growler.

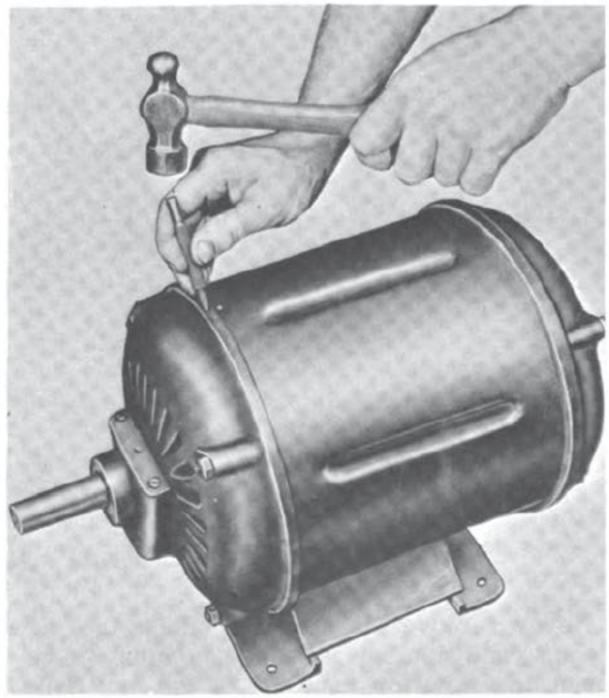


Figure 10-6.—Making punch marks on a motor frame and end bell.

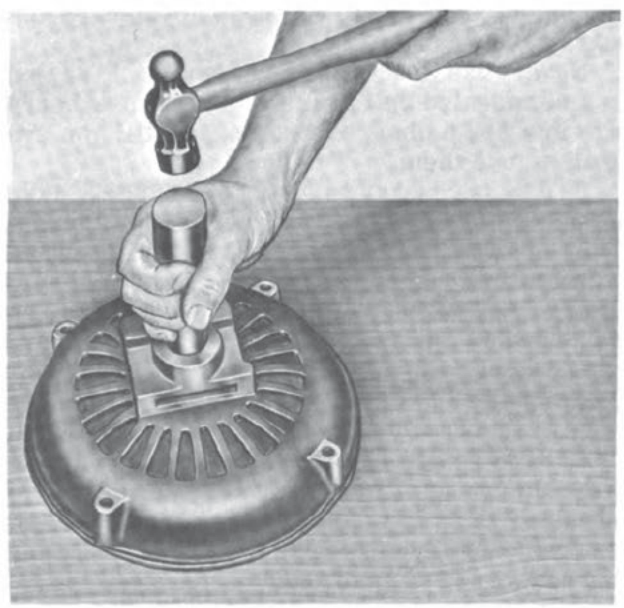


Figure 10-7.—Removing a sleeve bearing.

Procedures for removing BEARINGS vary according to the type of end bell and bearing assembly. Figure 10-7 illustrates a simple method of removing a sleeve bearing by first selecting and placing a sleeve-bearing arbor; the arbor is then tapped with a hammer. In figure 10-8, the bearing is a ball bearing. It is being removed, not by arbor plates, but by a hook type puller.

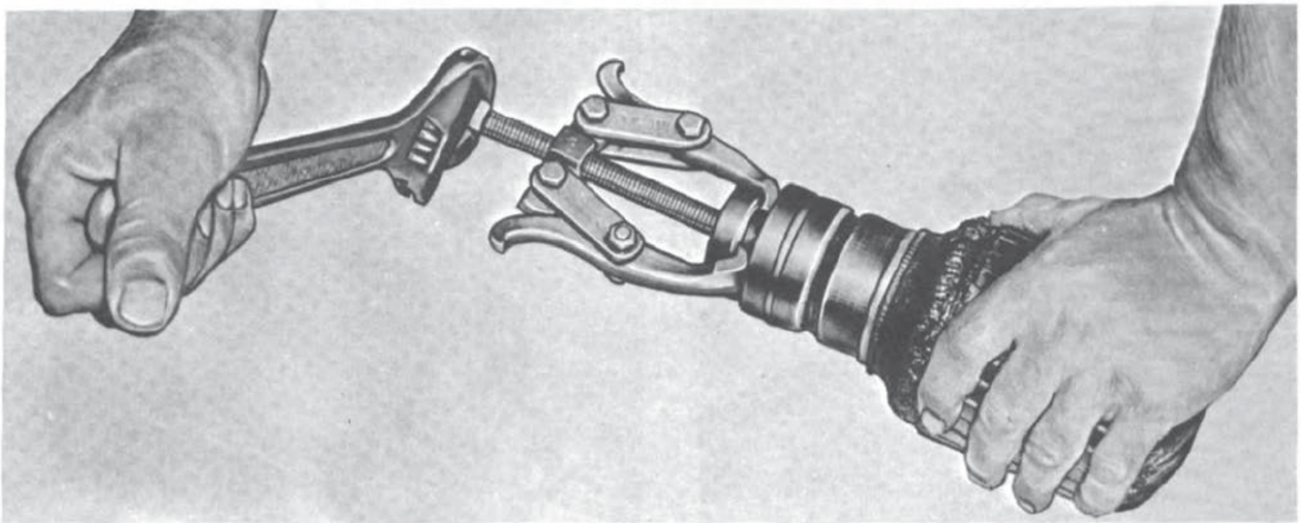


Figure 10-8.—Removing a ball bearing with a hook type puller.

Never remove the bearings unless they are in poor condition, or unless they must be removed to allow for removal of the end bells. If you are taking off a ball bearing, and plan to use it again, be careful to apply pressure to the inner race only. If pressure has been applied to the outer race, you will have to discard the bearing.

Never use a cleaning solvent on a sealed or a semisealed ball bearing. Store these bearings in a clean piece of waxed paper, till you are ready to use them.

If it is necessary to remove BRUSHES, take the precaution of recording angle and placement of the brushes and brush rigging, and clearance between brush holder and commutator (or slip rings). As a general rule, it is enough to place the brushes in the raised position; remove brushes only when this procedure is necessary to give access to other parts of the unit.

Always record the connections of INTERNAL SWITCHES before removing them. Make a note of the thickness of fiber washers; tag the parts, and wrap them in waxed paper. Do not attempt to dress badly burned contacts, or to repair any charred, cracked, or broken parts.

You must take particular care in removing ARMATURES AND ROTORS, to avoid damaging them. Protect yourself, too, by wearing canvas gloves while handling the shaft, to avoid getting cut on the keyways. Support the armature or rotor by its shaft, whenever possible, and do not allow its weight to rest on the commutator, coils, or rings. Figure 10-9 illustrates the proper method of supporting a small armature as you remove it from a motor or generator frame. Never roll or slide an armature to the bench or floor, since you might easily damage insulation or laminations.

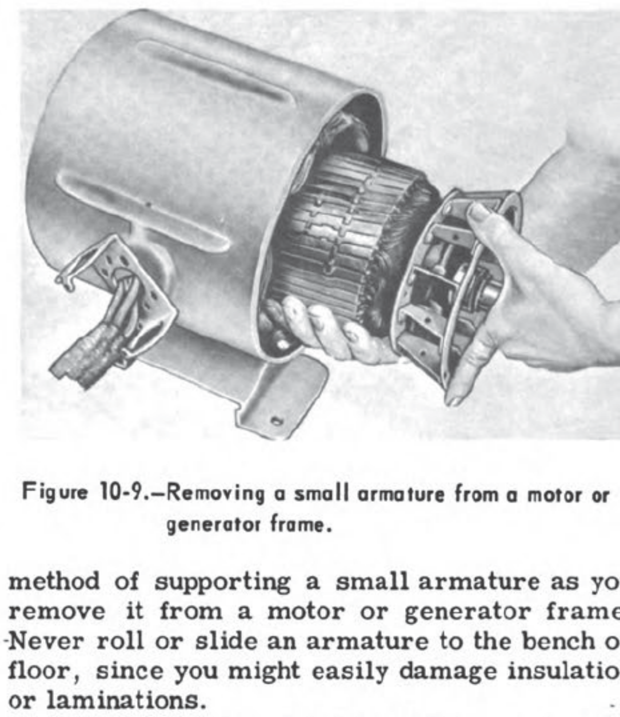


Figure 10-9.—Removing a small armature from a motor or generator frame.

Before removing POLE PIECES, record the relative positions of field coil assemblies, and the distance between pole surfaces. Tag the liners found between pole pieces and field frame to show type, thickness, and space occupied.

In unscrewing the slotted head screws, use the proper size and type of screwdriver; on hexagon-shaped head bolts, use the proper size and type of wrench. Any screw with a thread that is burred or stripped must be replaced. Lift

the pole piece out carefully, so as not to damage adjacent coils.

Once the generator or motor has been taken down, you can make the necessary repairs to the component parts. The more usual types of repair are discussed in the following paragraphs.

Commutator and Rings

Good commutation requires satisfactory electrical and mechanical contact between brushes and commutator, or between brushes and collector rings. Excessive sparking about the brushes, commutator bars, or collector rings is usually an indication of poor commutation.

The reason may be pitted surfaces, wrong type of brush, incorrect tension or alinement of the brush, unbalance of the armature and rotor, or wear from long use. The surfaces of the commutator and of the collector rings may be streaked and gummy because of oil vapor, oil, or grease; a blue or green tint to the copper may indicate the presence of chlorine or sulfur fumes.

Check the bars for burned condition, and for any irregularity or looseness. Check for high mica, or pitted condition. With the machine in motion, check the commutator bars for undue vibration.

Cleaning of commutator bars and collector rings should be done with a lintless cloth moistened with an approved solvent. Polishing is done with the machine in motion. Canvas or hard cloth wound and taped around a stick can be held against the commutator; or the polishing can be done by applying a light load for several hours, increasing the load gradually as brush contact improves. Never use a lubricant either during or after polishing.

Irregularities in the collector rings or in the commutator bars can be corrected by grinding the surfaces with a commutator stone. This type of dressing tool is illustrated in figure 10-10.

Where the irregularities are pronounced, a tool-type resurfacer must be used. Whichever device is used, the commutator or collector rings should be at operating temperature; therefore, do the grinding just after the machine has been on load.

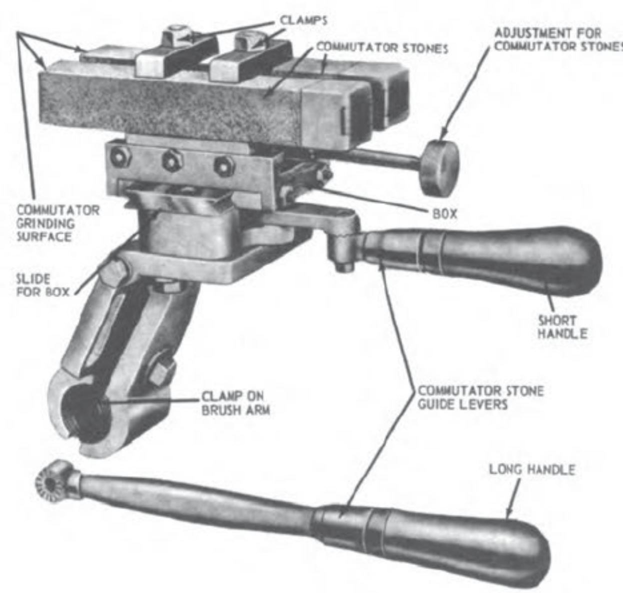
If you use a commutator stone, revolve the commutator to its rated speed, and apply the stone. After a few minutes, the surface of the commutator will be bright, except for the flat spots and the burned edges. Keep applying the stone until these dark spots become bright, showing that they are even with the rest of the commutator. However, be careful not to remove more copper than is absolutely necessary.

Grinding resurfacers are often equipped with a vacuum cleaner arrangement fitted to the stone. Unless such an arrangement is available, to catch the dust, you will have to place a protecting cloth hood or heavy paper over the ends of the windings.

If the roughness or distortion of a commutator is excessive, it will be preferable to turn it down in a lathe, rather than to try stoning or grinding.

First make sure that the armature is in good repair, and is approximately balanced. Place masking tape around the commutator risers, to prevent loose copper from working down inside the coil leads between armature wiring and commutator. Support the armature in the lathe, and make the cuts with a diamond-point cutting tool.

Because there is a certain give, or elasticity, to the support, a heavy cut may result in the cylindrical shape of the commutator being impaired. Again, a heavy cut can cause the turning tool to twist the commutator bars, and to make deeper cuts at one end than at the other. Take light cuts, therefore, even though more cuts will thus be necessary.



Courtesy Martindale Electric Co.

Figure 10-10.–Commutator stone dressing tool.

The lathe must be capable of turning the part to be ground at exactly its rated speed; if the grinding is done at a lower speed, any slight unbalance will cause the commutator to turn eccentrically, when run at rated speed. The usual cutting speed is 100 fpm; the feed should be about 0.01 inch; and the depth of the cut should not exceed 0.01 inch. (For the method of changing fpm to rpm, see appendix II of this training course.)

Insulating mica protruding from the slots between the commutator bars can cause wear, streaking, and breaking of the brushes. Remove this high mica by undercutting it with a power-driven flexible-shaft undercutter, after first removing the brush rigging. If a power-driven tool is not available, use a slotting tool, or else make a cutter by removing the teeth from a hacksaw blade, and forming one end. The straight end, taped, will serve as a handle.

Do not use lubricant, and do not cut too deeply. After removing the high mica, smooth off all burrs, and polish the commutator.

Poor balance in an armature can cause commutator failure. To check for concentricity, use a dial gage mounted on a brush holder, and with the contact tip of the gage contacting the top of the brush. Detach the armature from the machine, and rest the shaft ends on V-blocks. For a ball-bearing-supported armature, let the bearings remain on the shaft, and check the commutator with the shaft on V-blocks. The surface on which the V-blocks rest must be perfectly level, in every case.

For a commutator whose peripheral speeds are rounded 5500 feet per minute, the surface should be concentric to within 0.001 inch. For commutators with peripheral speeds of about 9000 fpm, the allowable tolerance is only 0.0005 inch.

A check should be made on the air gaps at commutator poles, and at main poles, to determine if there is any wearing or misalinement. You may take the air gap measurement by setting a reference point on the armature (or rotor), and revolving it to measure four points on the stator (or the field frame) with reference to it. An equally satisfactory method is to choose your reference point on the stator or field frame, and revolve the rotor or armature to measure four points on the latter, with reference to the stator point.

Correct tension on the commutator is usually determined at the time of manufacture. Tightening the commutator will not aline the bars in their original position, and if the commutator becomes too tight, some of the bars may buckle. Making ringbolts and locknuts too tight may result in pressing the V-ring through the mica insulation, thus short-circuiting the bars.

Brushes

Brush failure may result from a number of different causes: a rough commutator; an unbalanced (or eccentric) commutator; protruding mica; vibration resulting from loose bearings; improper adjustment of spring tension or of brush positioning.

The brush is a device for drawing off from the commutator the current generated by the armature. The brushes ride on the commutator, held there by brush holders. The spring is to force the brush to bear on the commutator with the required pressure per square inch of brush surface. The brush holders are mounted on a yoke or rocker arm, so that the brushes can be shifted about the commutator, but keep the same position with relation to each other.

It is evident, therefore, that any defect in the brush riggings, or maladjustment of the spring tension, can impair the correct contact between commutator and external conductors.

For maximum commutation, the brushes must be set in the holders with allowable clearance, the spring tension adjustment must be such as to provide the correct pounds per square inch (psi) for the type of brushes, the brushes must be properly spaced about the commutator, and they must be set at the right angle.

You cannot have an accurate fit of the brushes unless the brush completely contacts the commutator. Use sandpaper and a brush seater to obtain a proper fit.

Cut off the power supply, and lift the brushes that are to be fitted. Have a strip of fine sandpaper, the width of the commutator, and insert it (sand side up) between brush and commutator. Hold the sandpaper firmly to conform with the curvature of the commutator, and hold the brushes by normal spring tension.

Turn the commutator, if possible; otherwise, pull the sandpaper in the direction of normal rotation. However, if you use the latter method, you will have to lift the brush, and then replace it, between pulls on the sandpaper.

The dust resulting from the sandpapering should be removed by some type of suction machine or vacuum.

The brush seater must be applied while the machine is in motion, so be careful not to injure yourself. Touch the seater lightly, for a second or two, exactly at the heel of the brush. Figure 10-11 illustrates the correct procedure.

Since the brush seater is compounded of a loosely bonded, mildly abrasive material, you must take the same precautions (in removing dust, and afterwards cleaning the commutator and windings) as you did in the sanding operation.

Windings

For small motors, the coils may be wound by hand into the stator slots. Size and shape of the coils is best determined from the coil that was removed intact. The importance of recording accurate information during the stripping procedure will be all too obvious when you have a job of rewinding to do.

Before you strip an ARMATURE which may have to be rewound, record the winding data on a card. The information should include the following items: nameplate data of the machine, number of slots, number of commutator bars, number of coils in each slot, number of turns per coil, size of wire, pitch of coil, pitch of commutator, end-room measurements, type of winding (lap or wave).

As soon as the winding data card has been completed, make a test to determine whether a short, ground, or open exists.

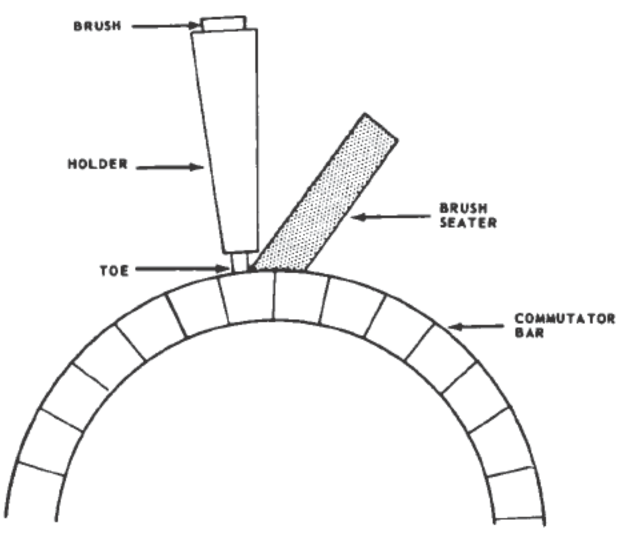


Figure 10-11.—Applying the brush seater to the commutator.

If it is found necessary to rewind the armature, you should first disconnect and remove the coils, at the same time recording the winding data that you could not obtain before stripping the armature. Preserve at least one of the coils in its original state, so that you may use it as a guide in forming new coils.

The two types of armature windings, lap and wave, differ in the manner in which the leads are connected to the commutator bars. Each type may be wound progressively or retrogressively, and each may be connected in simplex, duplex, or triplex.

Some of these terms need explaining. A simplex lap winding is one in which the beginning and end leads of a coil are connected to adjacent commutator bars. A duplex lap winding is one in which the leads of the coil are connected two bars apart. A triplex lap winding is one in which the end leads are connected three bars apart.

A progressive lap winding is one in which the current flowing in a coil terminates in the commutator bar adjacent to and BEYOND the starting bar. A retrogressive lap winding is one in which the current in the coil terminates in the bar adjacent to and BEFORE the starting bar. Figure 10-12 illustrates a progressive and a retrogressive lap winding.

A simplex progressive wave winding is one in which the current flowing through two or more coils in series terminates one bar beyond the starting point. A simplex retrogressive wave winding is one in which the current flowing through two or more coils terminates one bar before the starting point. Figure 10-13 illustrates a progressive and a retrogressive wave winding.

Before starting the rewinding, insulate the armature core. This is a very important step, since if the armature makes contact with the coils, you will have your work to do over. Clean the core slots and ends, and true up the laminations. Use fish paper or fuller board for insulation, and let it extend 1/4 inch beyond the slots, to prevent the edges of the laminations from injuring the coils. Figure 10-14 shows a method of insulating the slots.

Preformed windings should be used on large armatures, but it is more practical to wind small armatures by hand. The end room is very limited, and the windings must be drawn up tightly to the armature core. Figure 10-15 shows the method of winding an armature by hand. One

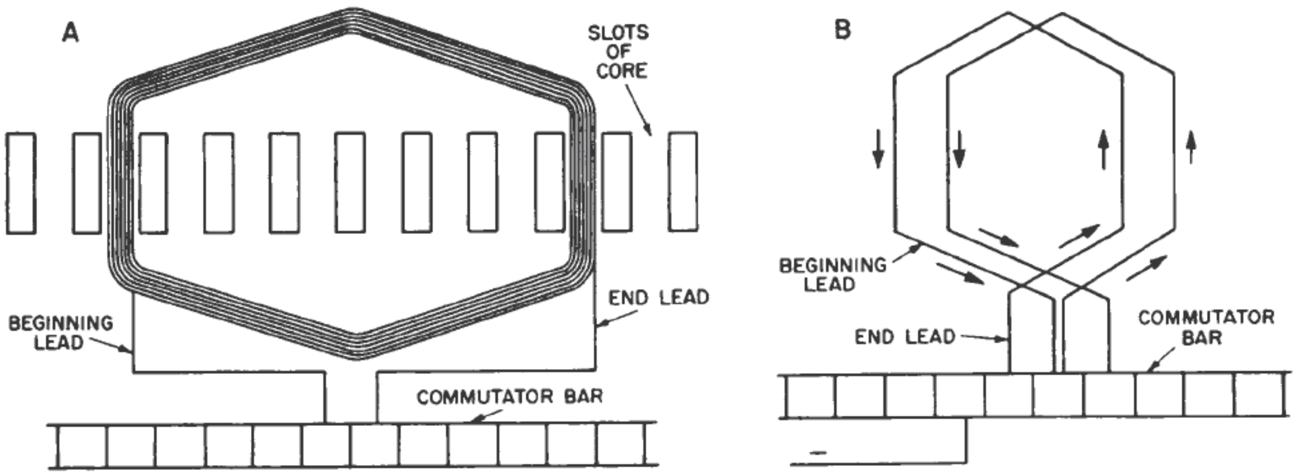


Figure 10-12.–Simplex lap windings: A, progressive; B, retrogressive.

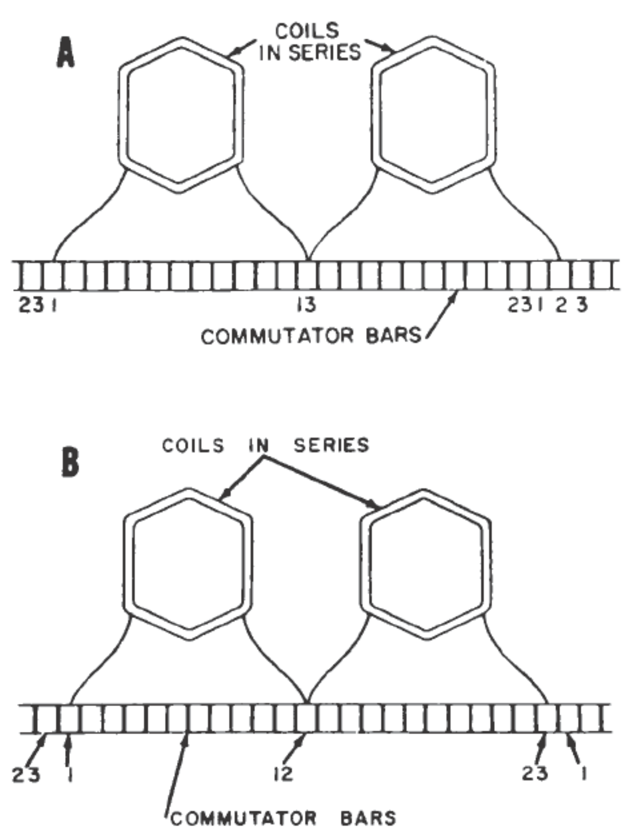


Figure 10-13.–Four-pole simplex wave windings: A, progressive; B, retrogressive.

armature is so small that the operator can support it in his hands; the other, a heavier type, rests upon supports.

New coils are taped with overlapping tape, and heated in an oven, at about 250 F, to drive

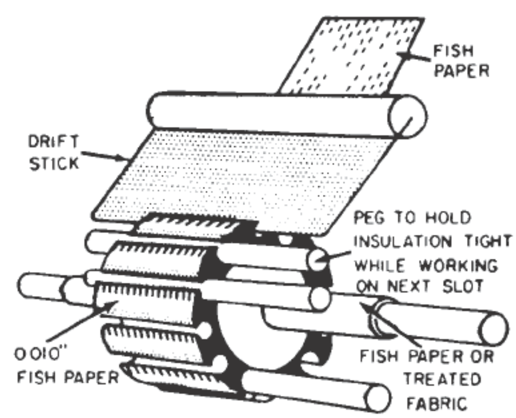


Figure 10-14.–Continuous strip method of insulating slots.

out any moisture. The baking time depends upon size of armature or field windings. After they have been dried out, they are dipped in a baking varnish, then are placed in the oven (at a temperature of about 220 F), and allowed to bake from 3 to 6 hours, or until the coil has a dry, glossy surface.

If the coil leads were properly identified when you took them apart, the process of connection is simple. It will be necessary only to bring the leads of the coils to the proper commutator bars, and to connect each coil in proper sequence.

You can strip the STATOR in much the same way as you would an armature. Use a blowtorch to burn the insulation from the wire.

When you remove the wire, keep the following record: nameplate data; number of poles; number

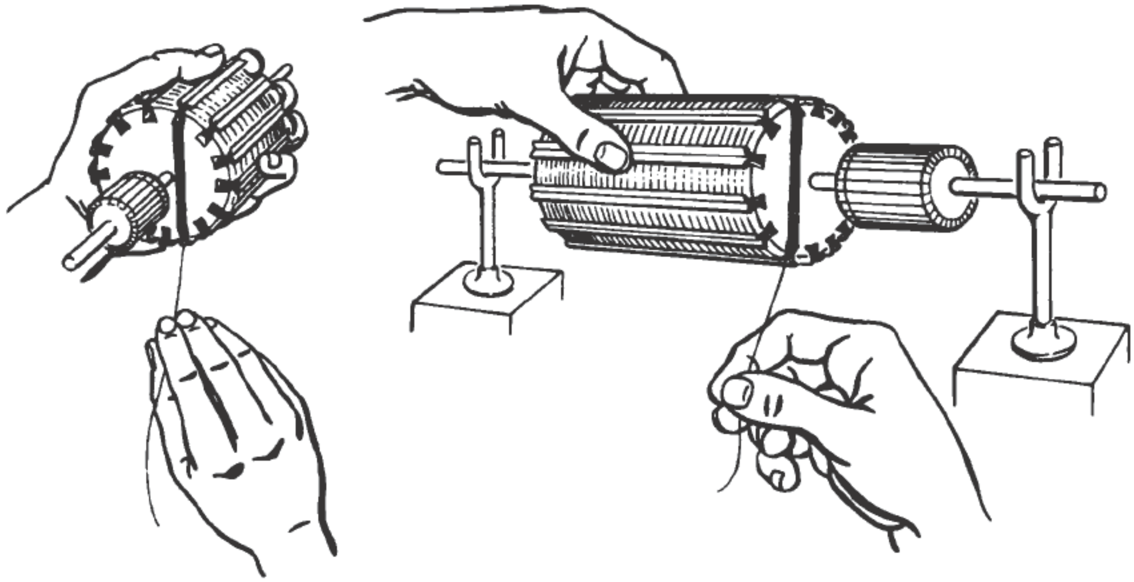


Figure 10-15.—Winding armatures by hand.

of slots; number of slots each coil spans (coil pitch); number of turns in each coil; size of wire in starting winding and in running winding; type of connection; type of winding, position of each in relation to the other; and slot insulation. Save at least one coil to provide dimensions for the new coils; and measure the end room of the coils before you remove them from the slot.

When you replace coils in the stator, make sure that each coil side extends beyond the slot at both ends, and does not press against the iron core at the corners. Before inserting the second coil side in a slot, be sure to insulate it from the coil side already in the slot. After all coils have been inserted, and the ends insulated, drive in the slot wedges.

There will now be two free ends for each coil, extending from one side of the stator winding. These free ends are connected in a series of groups; the number of coils in a group will depend upon the total number of coils, the number of phases, and the speed of the machine.

You can compute the number of coils in a group by dividing the number of coils in the stator by the number of pole-phase groups. For example, if the stator has 36 slots and 36 coils, and if there are 4 poles, and 3 phases, you will have 3 coils in series in each group. (Number of poles times number of phases gives the number of pole-phase groups.)

Connect the three coils in each group by connecting the outside lead of the first coil to the inside lead of the second coil, and the outside lead of the second to the inside lead of the third. Repeat this process in each of the pole-phase groups. If you made an error in dividing the number of coils into phase groups, it will come to light when you make these connections.

To connect the pole-phase groups together, you should have a diagram similar to the one shown in figure 10-16. Mark with arrows the direction of current flow through each pole-phase group. The current flow must reverse in direction for each successive group, so that there will be alternate north and south poles. The pole-phase connections may be in series, in parallel, or in a combination of series and parallel.

Rewinding of FIELD COILS is done with many turns of fine wire (relatively small current) for shunt coils, and with a few turns of large wire (relatively large current) for series coils.

Record the following data on the original coil: size of wire; dimensions of coil with and without tape; weight of coil without tape; and kind of insulation. If you can measure resistance in a similar coil in good condition, you can compute the length of wire required in the finished coil from this resistance and the wire size.

In winding the core, use insulating paper between layers, and leave sufficient free end on the wire to make the external connection. Be careful to keep the shape of the coil; but if the coil must be rounded to fit the inside curvature of the motor frame, bend it into shape before

applying varnish. If possible, use a form into which you can insert the coil, and press it into the necessary curve.

All windings—armature, stator, and field—must be tested after they have been wound, taped, formed if necessary, dipped, and baked. The tests should include those for grounds, opens, shorts, and polarity.

A simple polarity test can be made by sending a battery current through the coil, at the same time holding a compass several inches from the coil, but along its axis. When the south pole of the compass needle points toward the middle of the coil, you know that the coil face is a north pole. This polarity test automatically indicates an open circuit, if one exists.

When the stator or armature is assembled, with all connections completed and tested, and with the flexible leads for the connections to the power source attached, the stator or armature is ready for varnishing.

Where an armature is too large to be completely immersed in a tank of insulating varnish, it can be suspended over the tank, as indicated in figure 10-17, and lowered until the bottom coil slots are covered with the varnish. It can then be gradually rotated, until all parts have been well covered. Front and back ends of the windings, and the backs of the risers, can be sprayed. Then the winding, with commutator (or collector ring) end up, should be drained for about 30 minutes, at a room temperature of at least 68 F.

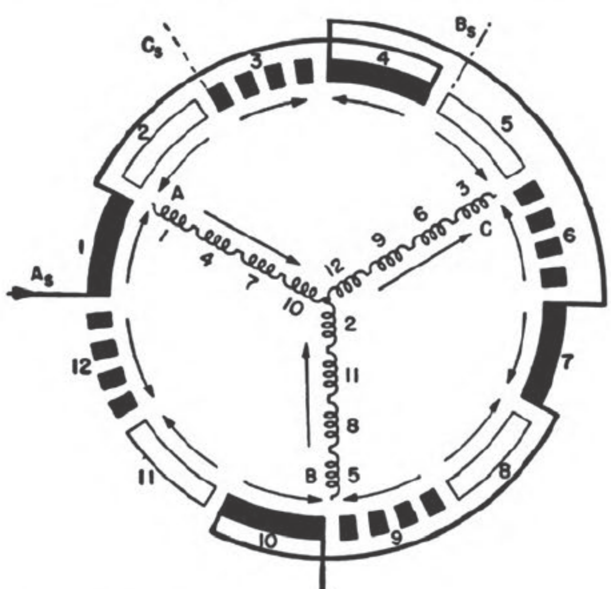


Figure 10-16.—Three-phase 4-pole winding for a 36-slot stator.

The varnish for dipping and baking should be at a temperature of 77 F to 90 F. If the repairs have been made under conditions of high humidity, give the equipment a preliminary baking, but allow it to cool in the oven before dipping. Immerse it in the baking varnish until bubbling ceases.

The first dip usually requires 15 minutes, and each additional dip requires about 5 minutes. Rotate the equipment slowly until all parts are well covered and bubbling ceases. Then remove it from the varnish and allow it to drain until all dripping stops. It is best to tape the commutator and shaft before dipping. At this time, wipe the metal parts such as the commutator and slip rings with a cloth dipped in thinner.

If your shop is equipped with a vacuum impregnation tank, apply a partial vacuum while the coils are immersed in the varnish. This draws out entrapped air and permits the varnish to penetrate the winding when the vacuum is released.

After the dripping stops, place the equipment in an oven at a temperature of 266 to 275 F. Bake for about 6 hours for each dip except the last, which should be for about 15 hours. Two dips usually are sufficient. The time of the bake specified is general and may have to be modified according to the size of the particular apparatus.

If an armature has been exposed to spray, dampness, or immersion, it will have to be thoroughly dried, and a megger test then made to show whether insulation between coils and frame is still satisfactory. If it has been

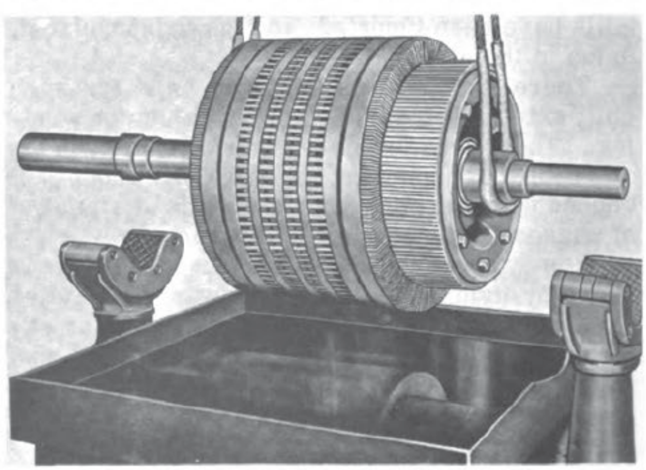


Figure 10-17.—Applying insulating varnish to armature windings.

exposed to salt water, it will be necessary to repeatedly wash it in fresh water before baking it.

If the insulation has suffered from dampness, but none of the windings has been burned out, wash the armature in an approved solvent, dry it by heating. Check for moisture and grounds, and then dip it in baking varnish. Never bake the armature immediately after dipping, but allow the varnish to drain before applying heat. Unless you do so, a skin will form on the surface of the varnish, and seal in the moisture from the solvent.

Circuit Faults

Many of the troubles that occur in electrical equipment may be caused by improper connections. You have already seen, from your study of the preceding pages, how important it is that the coils in a group be correctly connected, the groups be correctly connected to each other, and the external leads correctly connected to the power source.

Loose or broken connections, even though originally made in the proper manner, can render electrical equipment inoperative. A part of any good maintenance program is to check frequently upon the condition of all connections.

When you have trouble with windings, make a visual inspection first. Look for breaks in insulation or in wire. However, many troubles that occur in connection with windings cannot be detected immediately, and you will have to make certain tests, to determine the reason for failure. When you have tested for grounds, opens, and shorts, and have determined which of these circuit faults is present, you can disconnect the separate coil connections, and test each coil winding until you have located the defective one.

Make tests for GROUNDS on armatures and wound rotors as follows:

1. Growler test: Place the armature on an external growler connected to an a-c power source. Connect a lead to the shaft, and with the other lead test each commutator bar in turn, as the armature is rotated in the growler. If there is sparking evident, as the second lead makes and breaks contact, a ground is indicated. (For wound rotors, the lead must contact collector rings, in place of commutator bars.)

2. Lamp test: Connect one lead of a test lamp to a source of power, and the other lead to the armature shaft. Connect an additional lead to the other side of the power source, and bring the other end of this lead into contact with the commutator bars (or the rings) in turn. If the lamp lights, a ground is indicated.

3. Millivoltmeter test: Connect one side of a 1.5-volt battery to a commutator bar, the other side to a variable resistance that is in series with a commutator bar several bars away from the first. First set the resistance to its highest value, and touch the millivoltmeter leads to the connections; then adjust the resistance until the pointer is about three-fourths along the scale. Then connect one lead of the millivoltmeter to the shaft or core of the armature, and touch the other lead to a bar connected with the power source. A deflection of the meter pointer indicates the existence of a ground.

4. Megger test: Connect one lead of the megger to the shaft or core of the armature, and clamp the other lead to one of the commutator bars. Crank the megger, and watch the pointer; a reading of zero at any commutator bar indicates a ground, and a reading that approaches infinity indicates a high resistance ground. An ohmmeter may be used in the same manner; a deflection of the pointer, when the ohmmeter lead is touched to a commutator bar, indicates a grounded coil.

Test for grounds in stators and fields with a test lamp, an ohmmeter, or a voltmeter. One lead of the ohmmeter, or of the test lamp, must touch the stator frame, the other lead must touch the winding. If the lamp glows with full intensity, a ground is indicated; if the lamps glows with partial intensity, a partial ground exists. If the pointer on the ohmmeter deflects, the winding is grounded.

In using a voltmeter, you connect one lead of the meter to the power source, using a suitable fuse, and then connect the other lead to a lead from the stator frame. Then connect the frame to the grounded side of the power source. If the reading on the voltmeter is practically that of the source voltage, the winding is grounded. A partial reading (of source voltage) indicates a partial ground; a zero reading shows that there is no ground.

Test for SHORTS or OPENS on an armature as follows:

1. Growler test: Place the armature on an external growler connected with a power source. Lay a hacksaw blade on the top slot of the armature; a vibration indicates a short circuit. Move the hacksaw blade to the adjacent

slot on the left, then to the one on the right. Rotate the armature until the next three slots are on top, and test these three. Keep moving the armature until all slots are tested.

To determine if there is an open circuit, use a meter-indicating external growler. Move the test prods of the growler around the commutator, as described in the foregoing paragraph. No meter reading indicates an open circuit. A reading that is out of line with the readings for the other coils indicates a short circuit, or a high resistance joint.

2. Millivoltmeter test: Connect one side of a 1.5-volt dry cell to a commutator bar, and connect the other side in series with a variable resistance. The span between leads must be one-half the total number of bars for a 2-pole armature, one-fourth the total number of bars for a 4-pole armature, and so on. Adjust the resistance for three-fourths scale deflection of the meter pointer, and then test each pair of adjacent bars. As the meter leads are moved to the right, make sure that the left lead contacts the bar from which the right lead has just been removed. A noticeable increase in the meter reading indicates an open; a noticeable decrease indicates a short.

These tests can also be used on wound rotors, provided the coil ends are disconnected from the collector rings.

To check on stators and fields, for opens or shorts, you may use an internal growler connected to a rated a-c source. A noticeable buzz indicates a short. If you use an indicating-meter internal growler, a pointer deflection indicates a short. You can check for an open by deliberately shorting each coil; in that case, a buzz at any slot means an open circuit. If you are using the meter-indicating growler, NO DEFLECTION of the pointer indicates an open circuit.

TROUBLESHOOTING ON GENERATORS

As a general rule, a schedule of before, during, and after operation servicing will keep a generator in good condition. Proper attention should be given to slip rings or commutator bars, and to bearings. As long as these components are trouble-free, the machine will need very little overhaul or repair.

The slip rings should be cleaned and polished with canvas or other lint-free material, but they should never be lubricated. Commutators should be cleaned with sandpaper, and polished with canvas.

Lubrication of bearings must be done in accordance with the manufacturer's instructions. Some bearings may need daily oiling; sealed types may require greasing every 5,000 hours of operation.

Voltage regulators require occasional cleaning of contacts, and adjustment. The type of adjustment depends upon whether the voltage regulator is a vibrating-reed or a rheostat type. Adjustment of the spring tension may be needed now and then. In the vibrating contact type, the reversing switch should be operated every day, to prolong the life of the contacts. (On a generator that is only intermittently used, the reversing switch should be operated one day in one position, and the following day in the other position.)

Keep the alternators and the d-c generator (exciter) free of dirt and moisture. In some atmospheres, this may require a daily cleaning of all air passages.

Most troubles in generators are in commutators, armatures, and stators. Grounds are particularly bad, because they can burn out a generator. However, grounds and shorts are not the only source of trouble, by any means.

The following paragraphs indicate the possible causes for each of five specific faults in a-c generators: (1) failure of voltmeter to register voltage; (2) low voltage; (3) overheating of the exciter; (4) overheating of the alternator; and (5) noisy operation.

The voltmeter may fail to register voltage because of some defect in the meter itself; because of a short in one or more coils in the alternator shunt field; or because of some trouble in the exciter, such as a dirty commutator, brushes that make a poor contact, an open in the exciter field, or a short in the exciter armature.

Low voltage registered on the voltmeter may be the result of a defective voltage regulator; of a below-normal speed of the prime mover; of a short or ground in either the stator windings or the shunt field of the alternator; or of trouble in the exciter, such as dirty commutator or collector rings, or a short or ground in the armature.

Overheating of the exciter may be caused by wornout or otherwise defective bearings; by clogged ventilation openings; or by a short or a ground in the shunt field of alternator or exciter.

Overheating of the alternator may be caused by worn or defective bearings; by clogged ventilation openings; by overloading of the generator; or by a short or a ground in either the stator or the rotor coils.

Noisy operation is usually the result of worn-out bearings; of lack of lubrication of the exciter or the alternator bearings; of a short or a ground in the alternator stator; of improper connections at the alternator; or of overloading of the alternator.

TROUBLESHOOTING ON MOTORS

Many motor troubles arise from lack of periodic cleaning and lubrication. Operators do not always realize that dirt and dust provide a surface upon which grease, moisture, and even fumes may collect. Often the result is a breakdown of the insulation. Lubrication is necessary to prevent friction, with consequent wear and overheating, but too much lubrication can also cause overheating.

When a motor is sent to the shop for repair, make it your first procedure to check on the factors that are a part of a good system of preventive maintenance. Inspect not only for cleanliness and lubrication, but also look to see that nuts and bolts are properly tightened, that bearings are in good condition, that the armature is free to revolve, and that there is no mechanical obstruction preventing rotation.

These are items that should be checked by the operator, but you will often save time by looking for troubles caused by neglect of proper maintenance procedures. Very often a preliminary inspection with these factors in mind will be all that is required to put the motor back into service.

On any motor that comes to the shop for repair or overhaul, follow a definite procedure of (1) analyzing the trouble; (2) checking the data on the motor nameplate; and (3) taking the necessary data during disassembly, so that you will have no difficulty in rewinding and reassembling.

In looking for the source of electrical troubles in any type of motor, first make sure that when the motor was connected for use, there actually was a source of voltage available to it, and that the voltage corresponded to that indicated on the motor nameplate.

You should then inspect the motor to determine if the terminals are properly connected. Look also at the brush yoke, to see if it is properly clamped against the shoulder on the bearing housing, and is set on the running position for the desired rotation.

After connecting the motor to a voltage source, you can check the circuits for connections and contacts between motor switch and motor. Make sure that the starting device operates as it should, and that the correct neutral and the correct compensation are being used.

Eliminating grounds, opens, and shorts will probably comprise most of your repair duties. In this section, you will find general information that covers most of the repair procedures that you will follow. In the succeeding sections, you will find specific lists of the types of trouble you may encounter, according to the kind of motor. Where the difficulties require repair procedures not explained here, a note of the action you should take will follow the description of the difficulty.

To test for a ground on a three-phase motor, connect one lead of the test lamp to the motor frame, and the other lead to the leads of the motor. Figure 10-18 illustrates the proper connections. Note that the rated voltage of the lamp must be of the same value as the source voltage. By connecting the second lead of the lamp to each motor lead in turn, you can make a much more thorough check.

If the lamp lights, you know that the winding is grounded. Sometimes it is possible to locate the ground by visual inspection; but if not, locate it by disconnecting and testing each phase separately. For a Y or STAR connected motor, disconnect at the star point. In a delta connected motor, disconnect the phases at the leads.

When you have located the grounded phase, you must still determine which coil is grounded. To do this, disconnect the jumpers, and test each group separately. When the group has been located, open the coil splices and test each coil for a ground.

Sometimes a ground is caused by the edges of a lamination cutting into a wire, and the only corrective measure needed is to push the lamination back into place. Other causes are: a shift in the insulation, leaving the slot core uncovered; or a wire incorrectly placed between insulation and slot. If necessary, place a new coil in the stator.

A ground in any type of motor may be-caused by electrical contact between the windings and some part of the motor. For example, the windings may contact the bolts that fasten

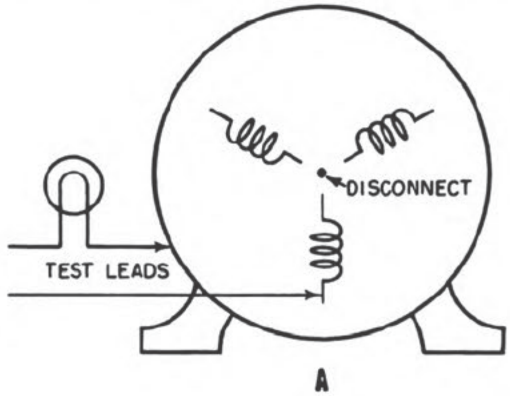


Figure 10-18.—Testing for grounds in a 3-phase motor.

the end plates to the frame, or they may press against the laminations at the corners of the slots. It is sometimes possible to see, by visual inspection, where the wires are touching the core. If not, try moving the armature back and forth, with one lead of the test lamp connected to the winding, and the other lead to the stator core. The lamp will flicker if the grounded point is temporarily removed, and there will usually be a spark at the point of the ground.

If moving the armature back and forth does not serve to locate the ground, you will have to test the pole windings. Disconnect the splices, and test each pole winding separately, until you find out which one is grounded. Rewinding the pole winding, or perhaps reinsulating the pole, will remove the ground.

In an induction motor, both armature and stator may have to be tested for grounds. Test the stator by the procedures just described. The armature windings and the commutator are tested in the same way. On motors where the brush holders are grounded to the end plates, you will have to lift the brushes away from the commutator before you test for a ground in the armature. However, it is always practical to disassemble a motor before any test of this type is made.

A grounded armature winding can sometimes be located by inspecting the slot ends to see if the coils are touching the iron core. If you cannot locate the ground in this manner, use the growler or the meter test. The growler test requires an a-c millivoltmeter, the bar-to-bar meter test requires a d-c millivoltmeter.

The growler itself is a primary coil wound on a laminated core. The metal of the mechanism under test completes the magnetic circuit. You can see this clearly from the illustration in figure 10-19. The coils in the armature act as secondary coils of a transformer.

Some growlers are equipped with test prods and meters. With these instruments, a short is determined by noting the current drawn in the growler; an open is detected by measuring voltage across the coil; and a ground is detected by measuring voltage between the ends of the coil and ground.

Place the grounded armature on the growler, with one lead of the meter on the top commutator bar, and the other lead on the shaft. Figure 10-19 illustrates the proper position. As soon as you apply alternating current to the growler coil, a voltage is induced in the armature coils, and there will be a deflection of the meter. Test each bar in succession, by turning the armature,

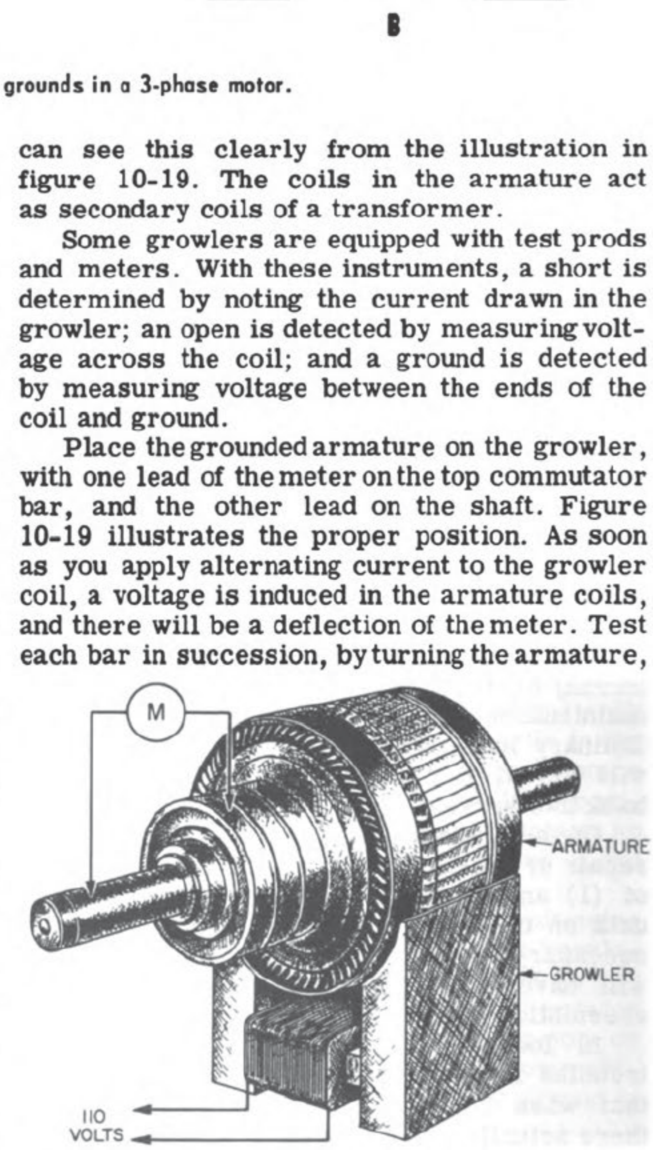


Figure 10-19.—External growler with armature in position for testing.

until the meter fails to deflect, thus indicating that the grounded coil is connected to the particular bar being tested.

To test for a ground in a lap winding, use the following trial method. Disconnect two leads from commutator bars on opposite sides of the commutator, and separate them. Touch one lead of a test lamp to the shaft, the other lead to the disconnected leads. If one lead causes the lamp to light, there is a ground on that half of the armature.

Pick one commutator lead from about the center of the grounded side, and test as before. In this way, you eliminate three-quarters of the armature from consideration. Continue in this manner until you have located the grounded coil.

The usual cause of the ground is defective insulation, or pressure of a lamination upon the coil. If the source of trouble is visible, it may be possible to remedy these faults easily and quickly. If it is necessary to rewind and reinsulate the winding, you may have to eliminate the coil from the circuit. Your decision will depend upon the necessity of the coil—that is, if the entire winding is desired in the circuit. After that, you can be guided by the time and expense involved in making the repair.

The electrical removal of a grounded loop wound coil from the armature circuit, while the grounded core itself remains in the armature, is a simple process. Disconnect the leads of the grounded coil from the two commutator bars, and put a jumper between those bars, to short them. Tape the disconnected ends of the coil, and let them remain in their original position, provided they do not contact the commutator.

If the coil were grounded in two places, there would still be induced currents in it. Test for a double ground by putting the armature on a growler and testing for shorts.

As mentioned earlier, you can test for an armature ground with a d-c millivoltmeter. Use a battery or other low voltage source of direct current, with several lamps connected into the circuit in series. Tie several turns of cord around the commutator, with the test leads placed under the cord.

Touch one lead of the d-c meter to the shaft, the other lead to a commutator bar. If there is a deflection of the meter, move the meter lead to another bar. Continue in this manner until the meter shows very little or no deflection; the coil connected to this bar is the grounded one. Figure 10-20 illustrates how this test is made.

To test for a ground in a commutator, attach one lead of your test lamp to the shaft of the armature. Touch the other lead successively to the commutator bars, passing to the next whenever you see that the lamp does not light. If a bar is properly insulated, there will be no sparking or arcing between the bar and the ground. If the lamp lights when the lead is touched to a bar, you have located a ground.

The usual cause of an OPEN circuit in a three-phase motor is a loose connection at splices or jumpers, or a break in a coil. The first step is to determine the open phase; after that, it is a simple matter to find the location of the open.

Use the test lamp to determine the phase. If there is an open, the lamp will not light. For a Y-connected motor, place one lead of the lamp at the center point, and the second lead on each of the phase leads, in sucession. For a delta-connected motor, disconnect the phases and test each one separately.

When you have determined the open phase, place one lead of the test lamp at the beginning lead of the phase, and with the other lead of the lamp touch the end of each group in succession. When the lamp fails to light, you will know that the group is defective.

Inspect the jumper connection, to see if the fault lies there. If so, reconnect and solder the wires. If the trouble is caused by a broken wire in the coil, cut the coil out of the circuit, if it can be spared. Replace the coil if it is necessary to the circuit.

An open circuit in a split-phase motor is usually due to a broken wire, or to a loose or

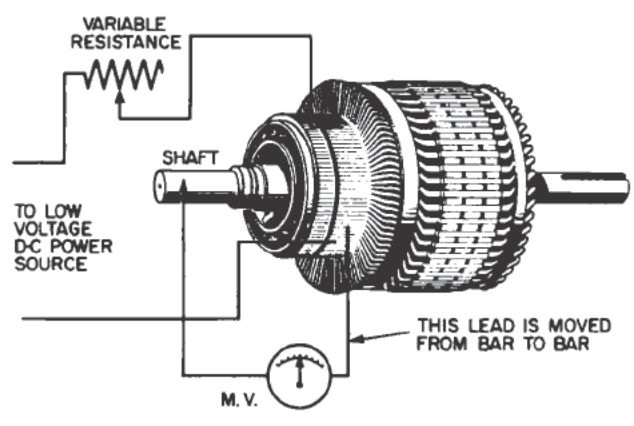


Figure 10-20.—Locating an armature ground by the bar-to-bar meter test.

dirty connection. However, the open may be in the running winding, the starting winding, or in the centrifugal switch.

To test for an open in the running winding, connect one lead of the lamp to one end of the winding, and place the other lead at the end of each pole in turn. Figure 10-21 illustrates the testing method.

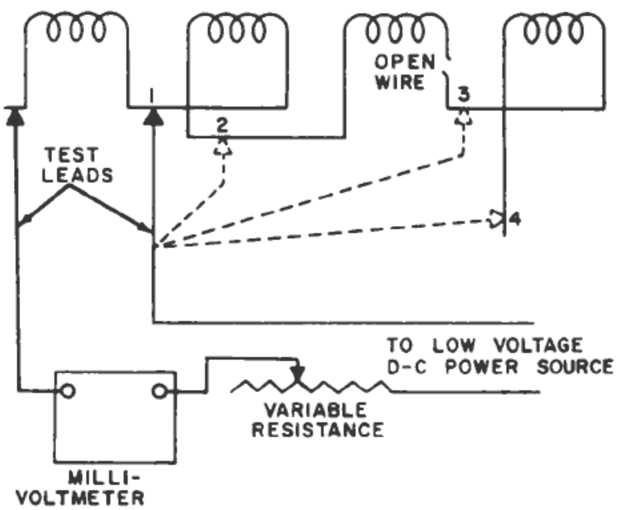


Figure 10-21.—Testing for an open in the running winding of a split-phase motor.

An open in the starting winding is tested for, and repaired, in the same manner as an open in the running winding. However, it may involve the centrifugal switch; for that reason, it is best to test the switch first, and only when that has been eliminated as the source of the trouble should you test the starting winding.

The centrifugal switch, if allowed to become dirty, worn, or otherwise defective, will almost certainly cause an open circuit, by preventing the contacts from closing properly. Sometimes the pressure of the rotating part of the switch against the stationary part will prevent the closing of the contacts.

Adding several fiber washers to the pulley end of the rotor shaft will push the rotor forward and thus cause the contacts to close. You may need to remove washers from the front end of the shaft. Be careful to keep the rotor core alined with the stator core.

The location of SHORTS in a motor can often be quickly determined by the heating of the shorted coil. In other cases, you will have to use the internal growler or a clamp-on ammeter.

For example, you can usually locate the short in a three-phase motor by connecting the motor to a power source, and letting it run for a short time. The defective coil will be much hotter than the others. Or you can use an internal growler, and watch for the vibration of a hacksaw blade or similar thin metal strip held at the end of each coil in turn. If you can connect the motor to a three-phase line, use a clamp-on ammeter to measure current in each phase; a higher reading in one phase usually indicates a short.

The same methods can be used to test for a short in a split-phase motor. Let the motor run for a time, then locate the hottest coil by feeling the poles. When the motor can be operated without a load, use the clamp-on ammeter; a short is usually indicated if the current reading is higher than current value shown on the motor nameplate. Make the growler test with an internal growler connected to a 110-volt a-c outlet. Disassemble the motor, place the growler on the core of the stator, and move from slot to slot, using the hacksaw method.

Another testing method is to determine voltage drop. Connect the winding to a low d-c voltage source, and take a reading across each pole. The pole that has the LEAST voltage drop is the shorted coil.

The strength-of-field test is made by passing current from a low d-c source through the winding, and holding a piece of iron against the core of each pole in turn. The pole that exerts the weakest pull on the iron is the one that is shorted.

A short circuit in an induction motor may be either in the stator or in the armature. First make a visual inspection, to see if the insulation is burned or charred. If so, it may indicate the location of the defective coil.

Test the stator by feeling for the hottest coil after you have allowed the motor to run for a short time. Other methods are the strength-of-field test just described, or the use of an internal growler to measure voltage drop across each pole.

On most motors at advanced bases, the armature can be tested with a growler. Cross-connected motors, however, must be tested with a millivoltmeter; a low reading indicates a short. A wave-wound armature should be tested on the growler. If the bearings are in good condition, you can move the armature by hand to test for a short. First remove the brushes from contact with the commutator, and then

connect the motor to a power line. With the brushes removed, the motor will not rotate. Turn the armature by hand, and if it has a tendency to stick at certain points, there is a shorted coil.

A coil, group, or phase improperly connected will result in a REVERSE. In a three-phase motor, an inexperienced man may easily make the mistake of connecting a phase in the wrong manner. Use a compass for testing; the compass needle should reverse itself at each pole.

Polarity in coil groups is also indicated by the compass needle reversing at each group. For a Y-connected motor, you should connect one lead of a low-voltage d-c line to the star point, the other lead to each phase in turn. Move a compass inside the stator to determine polarity. For a delta-connected motor, open a delta point and connect a low-voltage d-c source to the two wires.

A reversed coil can often be detected by a sight inspection. A more accurate check is to pass a low-voltage direct current from a battery through each phase, and place a compass against the core. The needle should indicate North and South at alternate groups; an indefinite reading at any group indicates a reversed coil in that group. The reason for an indefinite reading is that a very weak field results because of the opposing magnetic field built up by the reversed coil.

This section has provided you with sufficient information to enable you to detect the common sources of troubles in a-c motors. It will be helpful for you to have a brief list of the SYMPTOMS of trouble in various types of motors, and the cause of these symptoms. These trouble symptoms are listed separately for different types of motors.

Three-Phase Motor

1. FAILURE OF A MOTOR TO START is usually due to one of the following causes: the motor might have been connected to a source of voltage that was too low, or it might have been carrying too great a starting load; the field excitation may be too great; there may be an open or a short in one phase.

2. FAULTY STARTING may be due to: excessive belt tension or tight bearings, causing too much static friction; too much field excitation; an open circuit in one phase, causing the motor to heat up; wrong connections in armature windings; reversed phase in compensation.

3. HUNTING (unsteady operation) may be the result of: too strong a field; long lines (check on this point with operator); alternator speed was unsteady.

4. OVERHEATING of the motor may be caused by overloading, but it can also be the result of excessive armature current.

5. ARMATURE TROUBLES are usually caused by one of the following: a burned-out armature coil, the result of a short circuit; reversed polarity, the result of a wrong connection at a coil (the pole will buck, and require extra field current).

6. WEAK TORQUE is caused by: an exciter voltage that is too low, reversed field spool, an open or short circuit in the field.

Fractional H-P Motor

1. FAILURE TO START is usually caused by: poor contact where wires are connected to the motor terminals, poor contact of the brushes with the commutator, overloading of the motor.

2. HUMMING OF THE MOTOR and failure to start is due to: short circuit in the field windings, a ground in the connections, or in the cutout switch.

3. LOW RUNNING SPEED may be caused by: windings that are burned out, shorted, or grounded; ground in the cutout switch; the cutout switch fails to short circuit, because of dirt or corrosion in springs or pivots.

Split Phase Motor

1. FAULTY STARTING, where motor fails to come up to normal full speed load and blows fuses, may be caused by: friction in pivots and springs, open circuit in the starting or the running winding, ground or short in the starting or the running winding, ground or short in the cutout, grounded plate.

2. FAILURE TO START may be due to any of the following causes: insufficient voltage; defective fuses; grounds, opens, or shorts; failure of brushes to make proper contact; rotor not free to rotate in bearings.

3. HUMMING OF THE MOTOR and failure to start may be due to an open circuit or a ground

in the starting winding. The humming sound usually indicates that the running winding is not open; the motor can be started by rotating the armature by hand until it reaches normal rated speed.

4. LOW RUNNING SPEED may be caused by: wrong voltage and frequency, overload on the motor, a ground in the starting or the running winding, an open or a short in the field windings, connection wires that are too small.

5. HEATING OF THE ROTOR is usually caused by either of the following: overloading of the motor, or a break in the soldered connections of end bars.

6. HEATING OF THE WINDINGS may be due to one of the following causes: overloading of the motor; line voltage that is too low (if connection wires are too small, a drop in voltage will result); line voltage that is too high (a 5-percent excess on a 220-volt line, or a 10-percent excess on a 110-volt line, will burn out the windings); wrong frequency, as when a 40-cps motor is connected to a 60-cps current; wrong voltage connections to the motor; a short circuit or ground.

7. SPARKING AT THE BRUSHES is due to worn or loose brushes, or to dirty slip rings.

Induction Motor

1. FAILURE TO START may be due to any of the following causes: too low a voltage; too great a starting load; blown fuses; excessive friction caused by worn bearings.

2. FAILURE TO CARRY LOAD AFTER STARTING may be caused by a number of factors. Excessive friction, resulting from worn or overheated bearings, may increase the load to a point where the motor will not carry it. If a motor has squirrel cage windings, poor soldering of the bar joints can cause the joints to overheat, and so increase the armature resistance. In cases where some bar joints are good, some bad, the result will be unbalanced currents.

Another case in which the motor will fail to carry the load is when you have a single-phase current on the running position of the starter of a 3-phase motor.

3. INSUFFICIENT VOLTAGE may be the result of difficulties in the motor or in the service line. Inspect the fuses, switches, and connections, and test the line with a voltmeter. If the voltage was too low, make sure that the motor has not been hooked up to service lines that are too small. Check the actual voltage at the motor terminals.

If a check of the points already mentioned—voltage, phase, friction, fuses, connections—does not disclose the source of trouble in an induction motor, look into the motor itself. Check the connections, shaft, bearings, and the spacing of the brushes. The succeeding paragraphs suggest the factors that you should check, according to the trouble symptom.

4. LOW STARTING TORQUE may be due to poor contact in the energy circuit; to a partial short in the field or armature; to wrong positioning of brushes; or to reversed compensation.

5. HIGH SPEED AT NO LOAD may be due to incorrect spacing of brushes, or to wrong positioning of the brush yoke. If the no load speed is about one and one-half times rated speed, the trouble may be a poor contact in the compensating circuit.

6. LOW RUNNING SPEED may be due to overload, in which case it will be necessary to decrease the load, or to install a larger motor. Measure the load by ammeter, and compare the meter reading with the number of amperes listed on the motor nameplate as constituting normal full load input. Low speed may also be due to poor contact in the energy circuit, to incorrect spacing of the brushes, or to incorrect position of the yoke.

7. OVERHEATING OF THE MOTOR may be caused by a voltage that is either too high or too low, or by too low a frequency. Other than these input power characteristics, the factors that commonly cause overheating are overload, a projecting mica, incorrect brush pressure, wrong type of brush, incorrect position of yoke, reversed compensation, a short circuit in either the field winding or the armature or in both.

Check for a short circuit in the field winding, by removing the brushes and closing the main switch. A short will be indicated by excessive line current, and abnormal heating of the shorted part of the winding.

Check for a short in the armature by throwing in the line switch and slowly turning the armature. Any tendency for the armature to lock under each pole shows defective lining bearings, or a shorted armature. Use an ammeter to determine whether the armature is shorted; line current will be high and the meter will show a decided deflection as the short circuited coil comes under each pole.

8. RUBBING OF THE ARMATURE may be a sign of displacement of the iron; if the iron should cut into the slots, it will short or ground the windings. You should also check the bearings and replace them if necessary. Be careful to remove any foreign matter from the air gap.

9. WRONG BRUSH SPACING can be checked by means of the wiring diagram of the motor, although you can accomplish this check by counting the number of commutator bars between brushes. However, bars are not always the same width, and it is distance rather than number of bars that controls spacing. On a single-phase repulsion induction motor, the number of bars between energy brushes (short circuited brushes) and CORRESPONDING COMPENSATING BRUSHES should be the total number of commutator bars divided by the number of poles. The number of bars between an energy brush and an ADJACENT compensating brush will be only one-half as many. Your check should include the location of the brush yokes, and the condition of the brush rigging.

10. SPARKING AT THE COMMUTATOR results when brushes bind in the holder, or are so worn that they do not make firm contact with the commutator. Other causes are loose holders, incorrect tension, commutators rough or grooved, loose bars, open circuit in the armature, yoke wrongly positioned, incorrect compensation.

For loose bars, heat the commutator (in the oven, or by running the motor), tighten the shell nut, turn, and polish.

To test for an open coil in the armature, remove one set of compensating brushes, check to see that the yoke is in the running position, and then throw in the line switch. If the armature is in good condition, the sparking under the energy brushes will be in the form of short, light green sparks. An open coil is indicated if the sparking is in the form of long, tongue-like flashes that tend to follow the curvature of the armature. Let the motor run for one minute, then check for burned and pitted commutator bars; they will be adjacent to the open coil. Sometimes these long, vivid, noisy sparks are caused by projecting mica, rather than by an open in the armature.

PROTECTIVE DEVICES

Controllers, relays, solenoids, and other protective devices may be sent to the repair shop for overhaul and reconditioning. If possible, you should have the instruction manuals that have been issued by the manufacturers of such devices. There you will probably find the exact information that you will require to make necessary repairs.

Of course, with the information that you already have on the types of circuit faults that occur in electrical equipment, the methods to be used in making some repairs will be obvious. Remember, however, that all components of electrical equipment require the most careful handling. This may be especially true of various protective devices.

TROUBLESHOOTING ON SHOP EQUIPMENT

The CES ratings must also keep in good condition the various items of shop equipment that operate on electric current. Cleanliness and proper care are, here as elsewhere, the first factor in maintaining machines in good operating condition.

When difficulties occur, test for grounds, shorts, and opens as you have been instructed to do on the equipment used at other locations. For some types of shop equipment, such as meters, it may be necessary to send the items back to the manufacturer. Never try to make a repair unless you are sure that you know what you are doing.

Some mention should be made of the importance of knowing how to ground various types of equipment and appliances, so that personnel will be protected against the danger of electrical shock. At one time, it was customary to ground only those machines and appliances that operated from supply circuits of more than 150 volts. Standard procedure today requires the grounding of equipment operating from voltages as low as 50 volts.

Grounding in the range of less than 50 volts is at the discretion of local authority. You should find out what the policy is at your station or base.

The type of equipment that must be grounded naturally includes heavy-duty equipment such as X-ray machines, transformers, and generator station equipment. Motors must have their frames grounded. All noncurrent-carrying metal parts, such as metallic conduit, cable armor, switch boxes, and so on, must be kept as close as possible to ground potential, by providing a low resistance to ground.

As has already been mentioned elsewhere, water pipes make excellent ground connections.

Where such pipes are not close enough to serve, you will have to make use of ground rods. NEVER ground to steam pipes, or to fire sprinkler systems.

As a practical example of the need for grounding the cases or the enclosures of items that operate on low voltages, the following list of equipment to be grounded is provided here:

1. Shop Tools: Ground all drills, floor polishers, sanders, grinders, saws, soldering pots and irons, and similar tools.
2. Office Machines: Ground addressographs, mimeograph machines, paper cutters, typewriters, dictating machines, and calculators.
3. Heavy Appliances: Ground all refrigerators, stoves, washing machines, ironers, and sewing machines.
4. Galley Equipment: Ground broilers, grills, toasters, food mixers, coffee grinders and urns, and food freezers.
5. Appliances in Living Spaces: Ground radios, record players, TV sets, extension lights that are attached to portable cords, and desk lamps that are enclosed in metal surfaces.

Navy safety precautions require the grounding of equipment that operates on relatively low voltages; the ground connections must be not only electrically adequate, but also mechanically secure. All equipment and appliances should be periodically checked, at intervals of not more than one year.

The man in charge of the repair shop should be able to supply you with necessary instructions and notices issued as part of this safety program, or he should be able to tell you what these supplementary instructions require of you.

QUIZ

1. Why should you be careful in handling components of electrical equipment?

2. How many stator leads are there on most a-c generators?

3. What one procedure will go a long way towards keeping an advanced base generator in satisfactory working condition?

4. When you remove end bells during the disassembly of a piece of electrical equipment, you should provide for easy reassembly by
   (a) checking the end bells for nicks, and tagging them with the number of the apparatus
   (b) punch-marking frame and mating end bells, with a different mark for each end
   (c) placing them in containers marked with the numberplate data of the apparatus
   (d) storing the bells in a safe place

5. If pressure has been applied to the outer race of a ball bearing during removal, it will be necessary to
   (a) apply an equal and opposite pressure, to correct distortion
   (b) apply an equal pressure to the inner race
   (c) true the bearing
   (d) discard the bearing

6. Why should you wear canvas gloves when removing an armature from a machine?

7. Excessive sparking at commutator bars or brushes may be caused by
   (a) unbalance of the armature and rotor
   (b) a gummy condition of the commutator surface
   (c) poor alinement of the brushes
   (d) any of the above

8. Mica projecting from the slots between commutator bars can cause
   (a) serious vibration
   (b) tightening of the tension on the commutator
   (c) wear and breaking of the brushes
   (d) all of the above

9. Tightening the tension on the commutator is likely to bring about
   (a) buckling and shorting of the bars
   (b) better alinement of the bars
   (c) better contact with the external circuit
   (d) maximum commutation

10. The setting of the brush angle for commutators with speeds of 9,000 fpm should be
    (a) leading, at an angle of about 15 degrees

(b) trailing, at an angle of about 15 degrees
(c) leading, at an angle of about 35 degrees
(d) trailing, at an angle of about 35 degrees

11. A simplex progressive wave winding is one in which the

(a) beginning and end leads of a coil are connected to adjacent bars
(b) current flowing through 2 coils in series terminates one bar beyond starting point
(c) current flowing in one coil terminates in the bar just beyond starting point
(d) beginning and end leads are connected two bars apart

12. How do you compute the number of coils in a group for a 2-pole 3-phase machine?

13. What should be the direction of current flow in successive pole-phase groups?

14. After armature, stator, or field windings have been wound, taped, dipped, and baked, what 4 tests must be given to them?

15. Applying a compass close to, and along the axis of, a coil connected to a battery is a method of testing for

(a) opens and polarity
(b) polarity and shorts
(c) shorts and grounds
(d) grounds and opens

16. What is the objection to baking an armature immediately after dipping?

17. To test for grounds in stators and fields, you can use either a test lamp or a

(a) voltmeter or ohmmeter
(b) indicating-meter growler
(c) clamp-on ammeter
(d) internal growler

18. How often will sealed-type commutators require greasing?

19. What 3 steps are suggested as preliminary to repair or overhaul of a motor?

20. How can you make a thorough test for a ground on a 3-phase motor?

21. If the coils of a motor armature touch the iron core when they are placed in the slots, what will be the result?

22. If a clamp-on ammeter attached to a 3-phase motor running without a load shows a current reading higher than the current value on the motor nameplate, what is indicated?

23. What simple method can you use to make a check of brush spacing?

CHAPTER 11

SAFETY

Safety precautions should be a part of every operation performed by a Construction Electrician. Safety is never to be thought of as a separate and distinct function. The reason why it is discussed in a separate chapter in this training course is to ensure that all the service ratings will be made aware of the need of constant care in guarding themselves and their fellow workers from the hazards that are present when you work with electrical equipment.

Each man is responsible for observing all the established safety rules. He is also expected to use good judgment when instances occur for which no specific regulations have been recommended.

Safety for yourself and others involves the following factors: keeping working spaces free from hazard; wearing the prescribed safety clothing; giving full attention to the job in hand; operating equipment in accordance with safety precautions; knowing the first aid procedures to be followed in cases of electric shock or burns.

The safety precautions in this chapter have been assembled with the idea of covering practically all types of work done by the service ratings. It would be impossible to anticipate here every hazard or source of danger that may arise. You should consult other safety publications, especially the two listed below:

1. United States Navy Safety Precautions, OPNAV 34P1 (1953)

2. National Electrical Safety Code, Bureau of Standards Handbook H30, U.S. Dept. of Commerce (1948)

Make safety you personal concern. Whenever you observe a safety hazard, even though you are not involved in the work being done, call it to the attention of a responsible person.

It is advisable to make a prompt report of any unusual condition, in a generating station or substation, or in an underground or overhead cable system. Unusual conditions are all too often the source of a break in continuity of service; they may also endanger life or damage equipment. When they occur, the best procedure is to take immediate protective steps—not to wait until it is evident that they constitute a safety risk.

HOUSEKEEPING RULES

The use of sound common sense and of care can prevent accidents to personnel, and loss or damage of material or equipment. Keep the working spaces safe both for the men working there, and for any personnel that may pass through or nearby. Learn to observe the following safety rules:

1. Place tools and material where they cannot fall on anyone, and where no one is likely to stumble over them. Where material must be piled, have the pile neat and compact.
2. Never lean tools or material against a wall or other support that might give under the additional weight. Do not lean them against any support where they could be jarred loose.
3. When you leave a working space for any considerable time, store tools and materials in an appropriate place.
4. Wipe up any grease or oil spots in the working areas.
5. Place all flammable material, such as greasy waste, oil-soaked rags, or paint-covered cloths, in an approved waste can, for proper disposal.
6. If you must work on an icy or otherwise slippery surface, spread a layer of sand or ashes to ensure a firm footing.
7. When you work in a manhole or other excavation, you should always make sure that it is protected by some sort of guard. Any excavation that must be left open overnight should be barricaded, and supplied with warning lights.

PROTECTIVE CLOTHING AND EQUIPMENT

In company with any rating that works about machinery, the Construction Electrician

should be careful never to wear rings or other jewelry; to make sure that ties, flopping sleeves, or other loose clothing is not subjecting him to risk; to avoid wearing zippered clothing—or, if he must do so, to see that the zippers are covered; to avoid wearing caps with celluloid visors; and to wear gloves and goggles whenever necessary.

A lineman should always wear gloves if he is tending a reel for stringing conductors. Never work with the gauntlets of the gloves turned down.

Always wear rubber gloves, and goggles, if you are working on electrical equipment where you may be exposed to arcing. (It might be noted here that you should always hold your body as far away as possible from brushes, circuit breakers, or other parts where arcing may occur during operation or handling.)

Do not wear hobnailed shoes, or shoes with metal plates. When trimming trees for polelines, wear rubbers or rubber-soled shoes for climbing. Test your safety strap and body belt before using them; never wear a strap with stitching across it, or one that is mended with tape. If you are using climbers, check the gaffs to see that they are at least 1 1/8 inches long on the inner side.

Use the safety harness if you are going to work in a manhole where gas may be present. This harness is designed with about 25 feet of manila rope fastened through a ring at the back. This makes it possible to haul a man through the manhole in an erect position, if he should be overcome by gas.

KNOWLEDGE FACTORS NECESSARY TO SAFETY

Common sense is involved in all safety precautions, but you must have more than common sense to safely perform your various jobs. You must have a knowledge of how systems and equipments operate, of what elements of danger they present, and of the tried and tested ways of protecting yourself and others against those dangers.

We might say that accident prevention is a problem whose answer depends upon knowing the safety factors, organizing your job properly, and recognizing hazardous conditions. The nature of power distribution systems, and of overhead cable systems, exposes the Construction Electrician to the risk of a variety of accidents. Be cautious always when working in the vicinity of power lines or power equipment.

Not all danger of accident comes from sources of electricity. Never stand in the path of straining ropes or winch lines, nor where there is danger of being struck by falling objects. Check ladders and scaffolds to see if they are strong enough to support you. Secure ladders against slipping, before you climb them.

The common causes of accidents have to do with climbing poles, towers, or buildings; with handling taping oils and compounds; with charging batteries; and with working near energized circuits. When you have learned the proper procedures to follow in these lines of work, and the precautions that you should take, you have eliminated most of the sources of danger.

Climbing Poles, Towers, Buildings

As poles are being raised, it is safest to assume that there is danger of something slipping or breaking; stand as far back as the length of the pole, unless you are actually engaged in raising it.

The pike pole method of setting poles should not be used unless there are enough men to do the work safely. In using pikes, the men must stand far enough apart so that they will not interfere with each other. Never brace the pike pole on your stomach; if the pole shifted toward you, you would not be able to get clear.

Never climb a pole just set until it has been backfilled and tamped. Before going aloft, make sure that the pole can stand your weight, and then make a careful inspection of your body belt, safety strap, and climbers.

The body belt usually contains pockets for small tools. It is important to keep the tools in these pockets, for if you climb with tools in your hands, you may injure yourself, or drop tools on someone on the ground.

The safety strap is to secure you to the pole, leaving your hands free. It is always fastened to a single D-ring on the body belt, until you have actually passed it around the pole, when you are in working position.

Precautions

Taking care of your body belt and safety strap, and checking them before use, are precautions that should become second nature to

you. Do not use a belt or a strap if the leather loops are cracked or torn, or if the holes for the buckle tongue are worn too large, or if the rivets are not strong enough to secure the D-rings. The leather should be kept oiled with neatsfoot oil, and the belts and straps put where they will not be exposed to excessive heat or dampness.

Watch for any excessive wear of the leather directly under the roller of the safety strap buckle. Too much play between the sleeve and pin where the snap hooks are attached to the strap indicates excessive wear of the pin.

The leather of a safety strap must be at least 1/8 inch thick; but where the strap is doubled, an overall thickness of less than 1/4 inch is allowable, because of the extra strength of the doubled portion. Look to see that both ends of the strap are securely attached to a single D-ring. When you are in working position on the pole, you unfasten one end of the strap, pass it around the pole, and then fasten the loose end in the second D-ring.

Do not rely upon the click of the snap hook keeper when attaching the strap to the ring; always look to see that it is securely fastened. Keep the snap hook facing away from your body when it is engaged in the D-ring.

Do not use an improvised safety strap, nor one that has been lengthened by the addition of rope or wire. Never attach the strap to pins nor to crossarm braces. It is never advisable to place your safety belt above the highest crossarm, if that crossarm is near the top of the pole; the strap should always be at least one foot down from the top of the pole. Once the strap has been secured, lean back in it to test it, before you take your hands off the pole.

Climbers are used only when you are engaged in continuous pole climbing operations. While wearing them, be careful not to gaff yourself or others; and never wear them while riding in a truck, or otherwise going from one job to another.

Inspect your climbers for loose or broken straps, and for worn stirrups. Gaffs must be the right length, and properly sharpened. Keep them sharpened so that they will penetrate the pole to a depth that will ensure a safe grip, but do not sharpen to a needle point, as they will sink in too far, and make climbing difficult. It is best to leave a shoulder about one-eighth inch back from the point.

Procedures

After you have made a preclimb inspection—of the pole to be sure it will support you, and of your body belt, safety strap, and climbers, to be sure that they are in good working condition—you are ready to begin the actual climbing. Observe the following safe procedures. Grasp each side of the pole with your hands (this is to enable you to balance on the climbers); raise one leg about eight inches from the ground, and step on the pole with the gaff of your climber. Then raise your other foot from the ground, and walk up the pole. Do not jab the gaff into the pole; the weight of your body will be enough to sink the point deep enough for secure footing.

Never climb a pole while another man is climbing. Wait until he has reached his working position, and has placed his safety strap around the pole, before you begin to climb.

The tendency of a beginner is to watch his feet while climbing, but you should always look up. Keep your body at arm's length from the pole, and have your knee a good four inches from the pole at all times. If your knee gets too close to the pole, the gaff will cut out, and you will probably fall to the ground.

When you have reached your working position, crook one arm (your right arm, if you are right-handed) around the pole, and with your other hand unsnap one end of your safety strap from the D-ring. Pass the strap around the back of the pole, and grasp the end in your right hand. Grasp the pole with your left hand while you use your right hand to snap the free end of the safety strap into the second D-ring. Lean back against the safety strap before you take your hands off the pole.

While you are in working position, keep most of your weight on your right foot, with your left knee bent, and the left foot slightly higher on the pole. When you grow tired in this position, shift your weight to your left foot, until you can get your right foot into a more comfortable position.

Exercise the same care in climbing towers and buildings. In the case of steel towers, there is even greater danger than in the case of wooden poles; there is much more risk of receiving a severe electrical shock. Take precautions against having your elbow (unprotected by the leather shield that is provided by your gloves) accidentally touch the framework of a tower.

Climbing towers, however, is somewhat easier than climbing wooden poles, since steps are usually provided on a corner leg. Where these bolts are not provided, you will have to use skates.

In coming down from the pole, you should have free use of both hands. First, of course, you must unhook the safety strap, transfer the free end to your left hand (if you are right-handed), and fasten both ends of it into the left-hand D-ring.

Then break out one gaff by swinging the knee outward. Step down with the same leg, to a point about 12 inches below the other leg, and let the weight of your body force the free gaff into the pole again. Then break out the other gaff, and step down in the same fashion. Look at the gaffs as you place them in the pole, to avoid placing them in hazardous spots.

Keep hips, shoulders, and knees away from the pole. Do not descend while another man is climbing down the pole.

Handling Oils and Compounds

When splicing oil is used, there is a choice between cold oil method, and hot oil method. If hot oil is used, or paraffin, warn the splicer before you actually convey the kettle or pot to the working space. It is a safety precaution for him to be ready to receive the hot liquid when it comes.

Never move a pot of hot liquid if the liquid is within two inches of the top. When you carry it, be sure that the soles of your shoes are clean and dry, and walk with a sliding or shuffling movement.

In working with sealing and insulating compounds, be careful to observe the manufacturers' instructions with regard to temperatures. Heat slowly at first; you can increase the amount of heat later. Avoid the use of makeshift containers for heating; use a regulation explosion-proof kettle.

The use of a safety can for fueling furnaces reduces fire hazards. These cans are usually equipped with pressure-relief valves, so that extreme heat will not cause them to explode.

When soldering joints, or tinning conductors, you must be sure that the furnace is placed far enough from the manhole covers so that no hot metal can spill into the manholes.

Using a wet ladle, or a cold one, will cause the compound or the molten metal to spatter.

If you must raise the molten metal to a man working on a pole, use a handline, and steady the line so that the pot will not swing too much.

If you make use of an acetylene torch to seal small cracks and cuts, be careful never to use it underground, nor in any confined space. You should not even use it near the end of a pipe or conduit leading underground. A mixture of 3 percent acetylene (leaving the cylinder) with 97 percent air is EXPLOSIVE in a confined space. Maximum explosive effect is reached with a mixture of 7.7 percent gas to 92.3 percent air.

Keep the cylinder away from heat, and wear goggles when you are working with this gas.

Never carry a gas cylinder in the cab of a truck, or in a passenger auto. Carry a cylinder in a splicer's truck ONLY if the trailer is equipped with a special covered compartment, ventilated to the outside. If you must carry the cylinder in the body of an open truck, place the cylinder in a canvas bucket, and have a chain or a strap to prevent it from swinging. Make sure that a cylinder valve wrench accompanies the cylinder.

Carbon electrode soldering can be used to repair ring cuts and breaks in aerial cable, but it should not be used in manholes, because of the danger of igniting any gases which might be present.

Always wear impact goggles when you are soldering with carbon electrode apparatus. The sputtering action of the electrodes usually causes small particles of the solder to be thrown from the sheath.

Ventilation of Manholes

In working in or around manholes, be careful to ensure your own safety, and that of fellow workmen, by first checking the ventilation. Proper safety precautions require that a gas test be made by qualified personnel before the men may enter to do their work.

If gas is detected, the manhole should be ventilated with a power blower. It may be necessary to reventilate from time to time, to maintain safe working conditions. If any men working in the manholes are out of sight of those on the surface, the men above ground should make

periodic checks, to ensure the continued safety of those underground. This precaution must be followed in spite of consequent work delays.

When manholes are located in the vicinity of gasoline storage tanks, the check made on ventilation must be an especially thorough one, since there is the additional danger of leakage and fumes.

Probably it need not be stressed here that it is an elementary precaution never to take an open flame into or close to a manhole if it is suspected that explosive gases are present.

Charging Batteries

Dry cells, or primary cells, are those in which the zinc (the primary part) is gradually eaten away by the electrolytic action. These cells cannot be recharged. Secondary cells, such as the lead storage cell, lose their chemical action after a period of use; the two plates or electrodes (one of lead, one of lead oxide) are converted to lead sulfate, and the sulfuric acid that formed the electrolyte is converted to water. These secondary cells, however, can be recharged, by passing an electric current through them in the opposite direction to that of discharge.

You will make frequent use of lead storage cells, and should know the precautions that must be taken in the recharging processes. The chief factors for you to watch are the temperature of the electrolyte, the ventilation of the space where you are working, and the care that must be taken in handling acid.

Temperature

When a battery is fully charged, it should contain about 38 percent sulfuric acid, by weight, and the specific gravity of the electrolyte should be from 1.280 to 1.300. Temperature affects specific gravity, in that the electrolyte expands when heated, and its specific gravity reading is lowered. Readings should be corrected to a standard temperature of 80 F.

For each degree above 80 F, add 0.1 to the reading; for each 3 degrees below 80 F, subtract 0.1 from the reading. Necessary adjustment can be made by adding sulfuric acid to a mixture of low specific gravity, until the required reading is obtained; or by adding DISTILLED water to a mixture of high specific gravity. This adjustment should never be made except by an experienced man.

Charging time depends upon how long it takes to fully charge the battery. The charging rate is indicated on the battery nameplate. Slow down the rate if violent gassing occurs during charging.

Watch the temperature during charging, for heat is being generated both by the chemical action and by the internal resistance of the cell. Overheating can warp the plates, so do not allow the temperature to exceed 110 F for any length of time. If it goes as high as 125 F, reduce the charge.

Since the freezing point of a fully charged battery is minus 23 F, you have little to worry about in this connection, unless you are in an extremely cold locality. However, as the specific gravity becomes lower with use of the cell, the freezing point rises, and approaches 32 F as a limit.

Ventilation

Ventilation of the working space is important for your own well-being. Make sure that there is sufficient ventilation to carry off fumes before they can cause any ill effects. There is also a danger of explosion where ventilation is poor.

Handling Acid

Be careful in handling acid, because of the danger of burns. When mixing electrolyte, ALWAYS pour acid into water. Pour slowly, to prevent excessive heating and splashing.

Working Near Energized Circuits

Basic safety precautions have been discussed in the preceding chapters, in connection with the installation and operation of various electrical equipment. In this section, the fundamental rules for safety when working on or near energized circuits will be briefly summarized.

The major points to remember are: the safety rules in relation to various voltages; the proper use of hot-line tools; and the necessity for knowing when to use rubber protective equipment.

Voltage

An idea has become widespread that the voltage in a 115-volt line is too low to be harmful. Actually, most of the fatalities that have occurred in the Navy from electrical shock have been due to the victim's contact with a 115-volt line. Even a low voltage can be dangerous, given the right conditions of defective insulation, or dampness. Treat every electrical circuit, even those as low as 35 volts, as a potential source of danger.

Lines and equipment operating at over 300 volts must be deenergized and grounded before any work is started. An exception, however, must be made in the case of overhead lines. Work may be done on energized conductors and equipment operating at 300 volts and less, PROVIDED adjacent energized or grounded conductors and equipment are adequately insulated, or covered with approved rubber protective equipment.

If rubber blankets are used, inspect them for worn spots or holes, before undertaking any work.

When you are sure that it is safe to start work, you must still be careful to observe the following safeguards:

1. Tape or cover all bare places on one conductor before another conductor is exposed.
2. Open switches and remove fuses before doing any work on building wiring, motors, belting, shafting blowers, shop machine tools, or other machinery. Attach HOLD cards to the switches.
3. Be careful not to touch steam or water pipes when you are handling electric light cords or portable electric tools.
4. Never leave joints or loose ends of wires untaped, or protected in some other fashion.

Lines and equipment that normally operate at voltages between 300 and 5000 volts should be considered energized until the contrary is actually proved. Sometimes a visual check is sufficient to show that the lines are safe to work on; sometimes it is necessary to use a voltage detector. First apply the detector to an energized line, to make sure that it is indicating properly.

Overhead lines may be worked upon if you wear the required rubber gloves.

All exposed, energized, or grounded equipment or conductors within possible touching distance must be covered with rubber blankets, rubber line hose, or similar insulated barriers. If you must change your position while working, cover or barricade any other conductors or equipment that come within reach.

In addition, you must observe all the following precautions:

1. Deenergize circuits to be worked on, by opening switches; never open a ground connection at a ground pipe or a ground bus bar without making sure that it is disconnected at the point of contact with the equipment that it is intended to ground.
2. Treat wires being installed on poles as energized, if the poles are already carrying energized conductors of another circuit. Treat all spans of wire to be removed as energized. Use ROPE, not wires, for pulling in all new circuit conductors, and for lowering spans to be removed. (For conductors carrying more than 5000 volts, use a link stick to insulate the rope from the conductor.)
3. Ground the trucks carrying payout reel to be used for stringing wires near energized conductors.
4. Keep the ends of a tie wire coiled during installation or removal, to prevent accidental contact with energized conductors.
5. Make sure, by testing, that a primary or secondary wire is dead before removing it.
6. Make all possible connections to dead wires and equipment, before you make the final connection to the energized circuit.
7. Make the ground pipe connection first, whenever a ground wire on a pole is to be connected.
8. Open the operating circuit switch (if any) before working on oil circuit breakers.
9. Treat series circuits and series lamps as energized unless they are definitely isolated by disconnects.
10. Never open a series circuit at a point where work is in progress (that is, at lamps or other series circuit devices) without using a jumper to bridge the portion of the circuit that is being worked on.

Overhead lines operating at 5000 volts or more can be worked on with approved hot-line tools, but all other conductors and equipment at such high voltages must be deenergized and grounded before any work is done on them. Additional precautions that you should take are:

1. Perform all work on deenergized circuits between two sets of grounds, using grounding chains or a similar device. These grounds should be placed in a specific manner—one on

the first pole or structure toward the energy source, and the other on the first pole toward the load.

2. Make the GROUND connection first, in attaching grounds; disconnect the ground connection last, in removing grounds.

3. Never ground a supposedly dead circuit without first testing it with a switch stick, for static discharge.

4. Do not work near energized equipment at a substation until suitable barriers and warning signs have been installed.

5. Remove substation apparatus from service before you do any routine cleaning, maintenance, or repair upon it; place hold cards on the main and control switches.

6. Do not perform any work on electrical apparatus until the man in charge of your crew has proved the circuits dead, and the equipment safe to work on.

7. Do not touch, or even closely approach, reactors until you are sure that they have been disconnected from all live lines, and securely grounded.

8. Never move energized cables carrying voltages above 12 kilovolts; in the case of energized cables at voltages under 12 kv, never raise, lower, or otherwise move them a distance of more than 18 inches.

9. Discharge electrolytic and oxide-film lightning arresters by grounding and short-circuiting the horn gaps before touching them.

10. Maintain a minimum body clearance of 1 foot from energized lines and equipment at operating voltages of from 5 to 7.5 kv; maintain a minimum distance of 2 feet from energized lines and equipment operating at voltages from 7.5 to 12 kv; in the remote event that you will be working on lines energized at voltages above 12 kv, add 1 foot clearance for each additional 20 kv.

Hot-Line Tools

As mentioned before, you will have to use hot-line tools in working on overhead lines operating at 5000 volts or more. To ensure adequate protection, these tools have specially treated, highly insulated wooden poles, tipped with the various implements. In repairing energized lines with these tools, you should NOT wear rubber gloves, since they make detection of brush discharges impossible.

Do not trust to the insulating value of wooden poles; use as much caution as if you were working on a steel tower. Certainly you should never catch hold of a brace or other metal attachment. Never hold a live wire clear of another lineman on the pole, but instead secure it with hot-line tools and clamp it in place.

You should never change your position on a pole until you have looked around, and have warned the other crew members of your intention. When you are moving live wire, stay below the wire until it is thoroughly secured in a safe working position. Do not work more than one conductor at a time. Take special precautions on poles having guy wires.

It is the responsibility of the Construction Electrician First Class, and the Chief Construction Electrician, to see that men are not required to perform hot-line work under hazardous weather conditions. Of course, emergency work must be accomplished under adverse conditions, oftentimes; but in general, work with live-line tools should be stopped when daylight ceases, or when rain, snow, fog, or electrical storms threaten.

Rubber Protective Equipment

It is the responsibility of the Chief Construction Electrician to decide when equipment must be sent back to laboratory or manufacturer, for electrical tests. Each man, however, should frequently make a visual check on his own equipment, to be certain that it is in good condition.

Rubber equipment is, in many cases, the only safeguard between you and severe electrical shock. Take the best possible care of blankets, hoods, hose, and gloves. Do not carry such equipment in toolbags, or in any compartment with tools and other equipment.

Wear approved and tested rubber gloves when working on or within reach of energized conductors operating at voltages between 300 and 5000 volts. Wear them while working within reach of another man who is near such energized lines, or equipment. Wear them while cutting a supposedly dead cable, or while testing primary or secondary sides of supposedly burned-out transformers.

When applying or removing rubber blankets or other rubber protective equipment, never get into a position that could cause contact with live wires or equipment.

Wear rubber gloves when you are tending reels, or where wires are being strung or removed in the vicinity of other wires carrying from 300 to 5000 volts. Never remove your gloves until you are entirely out of reach of any energized conductors or equipment.

At the end of the day, you should wash your rubber gloves with bar soap and water. Dry them thoroughly before you put them away. Roll (do not fold) rubber blankets. Store rubber hose in containers.

FIRE PREVENTION

Certain basic precautions should always be observed to prevent the occurrence or the spread of fire. You have already been instructed as to the safety measures to take in using molten lead or other compounds, or in working with an acetylene torch. However, there are a number of other precautions which you should follow.

It is suggested that you learn the following 12 rules, and form the habit of practicing them from the first day that you are assigned to a Construction Electrician billet.

1. Deposit all flammable waste in approved metal cans provided with self-closing covers; see that these cans are emptied daily.

2. Although gloves are required for many jobs done by the CE ratings, you should NOT wear them while filling furnaces or torches, or when handling gasoline-soaked rags.

3. Do not fill a furnace or torch while it is hot; do not start a blowtorch until the gasoline in the priming cup is practically consumed.

4. Place furnaces and blowtorches where they will not be in a position to ignite surrounding material. Use a metal plate as a foundation, if necessary. Never leave a lighted furnace or a blowtorch unattended.

5. Avoid dropping hot solder on combustible material.

6. Release the air pressure from the gasoline tanks of furnaces or torches after use, and before putting them away.

7. Keep flammable liquids in approved safety cans, equipped with self-closing covers. Even in safety cans, never store more than one gallon of such liquids inside a building.

8. Use canvas or asbestos shields to protect combustible surfaces in the vicinity of welding operations. Keep fire extinguishers (water or soda-acid) near at hand, and maintain a watch for sparks that might lodge in cracks or other out-of-the-way places.

9. Do not use gasoline as a cleaning agent; for safety, it is best to use a low-hazard solvent.

10. Never use a flammable liquid for starting fires in rubbish or in salamanders (portable stoves).

11. Keep driveways, doors, aisles, and other approaches clear, so that there will be no obstacles to bringing in fire apparatus or equipment, if it should become necessary.

12. Notify the base fire department at once, when a fire extinguisher has been used, so that it can be recharged or replaced.

RESCUE AND FIRST AID

The very best service that you can render to yourself or to your fellow workers is to prevent any accident happening in the first place. Warn fellow workers who accidentally (or knowingly) place themselves in positions of danger. On the job, never indulge in scuffling, practical jokes, or horseplay; even unnecessary conversation should be avoided during duty hours.

Personnel engaged in the various types of electrical work should have at least an elementary knowledge of first aid. They should know what to do—and, equally important, what NOT to do—in giving artificial respiration, and in treating arterial bleeding, burns, cuts, sprains, bruises, and skin irritations from contact with creosote. They should have a fair idea of the difference between cases of shock, fainting, and gas asphyxiation.

There should be a first aid kit in all electrical shops, and on all trucks working out of those shops. Minor cuts and injuries may be treated on the job site, but a report should nonetheless be made, in case the injury is more severe than first appears. All CE ratings should be familiar with the arrangement and the use of the first aid kit.

Contact With a Live Circuit

The first thing to do, when a man comes into contact with a live circuit, is to remove him. If possible, you should at once turn off the voltage. Do not try to drag him away from the energized conductor or mechanism, since you may yourself become a victim. Use rubber gloves, or some similar nonconductor to free him.

Electric shock usually will stun the nerve center at the base of the brain, and the man will have ceased to breathe. Use any approved mechanical resuscitator to restore his breathing; but do not waste time waiting for one. Begin at once to give him artificial respiration. The method may be the one currently approved—that of breathing into his mouth. If you know only the method of applying pressure to his ribs, to assist his lungs in sucking in fresh air, use that method.

Artificial Respiration

All personnel engaged in electrical work must be thoroughly trained to apply respiration both in the prone-pressure method, and also pole top resuscitation.

On Ground Resuscitation

On ground resuscitation requires that you place the victim prone on the ground, face down. First, however, you should loosen any clothing that is tight about his neck, and you should make sure that his mouth and throat are free of foreign substances and of mucous. You should then follow this step by step procedure:

1. Drop to one knee. Bend victim's elbows and place his hands one over the other. Place his head on his hands. Turn his face to one side so that you can watch his face at all times to see that the tongue does not fall back into the throat.

2. GET YOURSELF IN POSITION—Kneel at the victim's head close to his arm. Kneel on either knee or both—whichever is most comfortable and gives you the best balance.

3. Place your hands just below the shoulder blades, the heel of the hands on an imaginary line drawn across the body just below the armpits. Fingers are spread wide, thumbs pointed toward the victim's spine with the tips just touching each other.

4. Now begin the sequence of operations necessary for artificial respiration.

a. Rock forward. Allow the weight of your body to press downward on your hands—and on the victim's back just below the shoulder blades. Keep your elbows straight; pressure should be almost directly downward. Lean forward only until you are in a position with your shoulders immediately above your wrists. Make sure that you make the pressure slow, steady and equal on both hands. Pressure should not be sudden or jerky.

DO NOT APPLY TOO MUCH PRESSURE. This is especially important if you're large and the victim is small or thin. You might break his ribs if you are not careful.

Release pressure quickly. "Peel" your hands from his ribs without giving any extra push with the release.

b. Rock backward and, at the same time, slide your hands up the victim's back and cup them under his arms just above his elbows. Do not grip his arms tightly or pinch into the flesh.

c. Draw his arms upward and toward you. They will be lifted naturally as you rock back. Do not pull. Raise the arms only until you feel resistance at the shoulder blades. The arm lift pulls on the chest muscles, arches the victim's back, and relieves the weight on his chest. This causes air to be sucked into his lungs.

d. Lower the victim's arms gently. Don't drop his elbows hard on the steel deck or ground; there is some danger of chipping the bone and there is no need for the victim to wonder after he comes to why his elbows are so sore.

Follow through on this cycle, letting each step take about 1 1/2 seconds, or 6 seconds for the complete cycle. Keep the action continuous, steady, and uniform. Do not give up too soon; it can be a matter of hours before the victim starts to breathe on his own.

There should be a relief operator to take over when you are tiring. Have him kneel on your right, with his right knee next to yours, and let him go through the motions with you a few times, to get the rhythm. Then drop out of the way to the left, so that he can continue the cycle without break.

Watch the patient when he starts to breathe on his own, and be ready to start artificial respiration again if he stops. Even after he has definitely come to, keep him lying down, and warm. To let him stand, or even sit up, may put a severe strain on his heart.

Do not give him anything to drink until he is fully conscious, and can swallow without danger of strangling. Then (if no doctor is present) you may give him a teaspoonful of aromatic spirits of ammonia in a small amount of water; or a little hot coffee or tea, if no spirits of ammonia is available.

On Pole Resuscitation

When there would be considerable delay in lowering a victim of electrical shock to a place

where he could be stretched out prone, it will be necessary to use the on pole (or POLE TOP) method of resuscitation. The step-by-step procedure is as follows:

1. Clear the victim from the electrical contact.
2. Take a position on the pole just below him, and place your safety strap about the pole at a point just above his spurs. He, meanwhile, is supported by his safety strap.
3. Work your way upward, with your safety strap between his legs, and his body between you and the pole. This gives him the additional support of your safety strap.
4. Remove from his belt any tools that could interfere with resuscitation. Clear his mouth, and pull his tongue forward.
5. Place your arms around his waist, with your thumbs below his lower ribs, your hands on his abdomen, and your fingers touching.
6. With your arms and hands, compress his abdomen with an upward motion. At the end of the stroke, your hands are cupped, with your fingers depressing his abdomen under his breastbone.
7. Rapidly release the pressure; then reapply it. Pressure should be applied and released at a rate of about 12 to 15 times a minute, until the victim can be lowered to the ground, or until he regains consciousness.

If another lineman is available, he can be of great help to you. He can get on the opposite side of the pole, and as you give the treatment, he can slide your safety belt gradually down, as you tell him. In this way, the unconscious man can be brought down to the ground as soon as possible.

Injuries From Burns

The main dangers from burns are shock and infection. A prompt application of first aid methods should prevent either of these conditions from developing.

If any ACID is spilled on the skin, wash it off with a liberal amount of water; then wash the spot with a borax-and-water or a soap-and-water solution. If no burn results, you need not report the accident; but if the acid has caused a burn, you must report it. If acid splashes in your eyes, immediately report to the doctor or to the sick bay.

The most likely source of burns in your work is the accidental contact with live equipment. In case of such burns, suffered by yourself or by a fellow workman, proceed as follows:

1. Dress MINOR BURNS immediately. Apply a thin coat of sterile vaseline to the burned area. Cover with a sterile bandage. Make the bandage firm and secure to protect the burn from air.
2. SEVERE BURNS cause extreme pain. This pain may be reduced by the use of morphine. Under normal conditions, morphine should be given only by qualified medical personnel. In an emergency, you may have to give it. Morphine is put up in a small tube with a needle at the end. This tube is called a SYRETTE. The drug is given by inserting the needle into the thigh or the outer side of the arm and squeezing the contents of the tube. Only a quarter grain should be given to relieve pain. NEVER give morphine to a person with a head injury, even though he is suffering from extensive burns.
3. SHOCK always accompanies a serious burn. Treat the victim for shock before attempting to treat the burn. After relieving pain as much as possible, place him in a prone position so that his head is slightly lower than his feet. Make sure he is warm; cover him with a blanket if necessary. Do not overheat him, but remember that exposure to cold will cause shock to become worse. If a medical officer will be available within about three hours, do not attempt to treat the burn. If more than three hours will elapse before medical personnel is available, you should dress the burn.
4. Remove the victim's clothing, being very careful not to cause further injury. If clothing or foreign matter sticks to a burn, do not attempt to pull it loose. Do not allow absorbent cotton, adhesive tape, or any similar substance that might stick, to come in contact with the burn. Do not use iodine or any other antiseptic on a burn. Use only sterile gauze, coated thinly with sterile vaseline. Make the strips of gauze from two to three inches wide. Wrap the gauze smoothly and gently around the burned areas, and then cover with a roller bandage. Make the bandage firm, but not tight enough to cut off circulation or to interfere with breathing. Do not disturb the bandage after it has been applied.

When burns are extremely severe, have the victim drink a cup of warm water provided he is conscious, can swallow, and has no internal injuries.

QUIZ

1. Why should every man be ready to make a prompt report of any unusual condition in a generating station or cable system?

2. When you leave a working space for any considerable time, what should you do with tools and materials?

3. If you are not actually engaged in raising a pole, where should you stand while it is being lifted?

4. Name 4 precautions recommended as advisable before you go aloft on a pole?

5. In securing your safety belt to the pole, you must make certain that it is

   (a) between two crossarms
   (b) below the topmost crossarm
   (c) a minimum distance of 1 ft from the pole top
   (d) a minimum distance of 3 ft from the pole top

6. If you are working on poles with another man, the safest procedure is to

   (a) wait until he has ascended at least 6 ft before you start climbing
   (b) climb directly behind him, so as to support him if necessary
   (c) climb on the opposite side of the pole
   (d) wait until he has reached his working position before you start climbing

7. When moving a pot of hot oil or paraffin for splicing, make certain that the liquid is

   (a) a minimum of 2 in. from the top of the kettle
   (b) a minimum of 6 in. from the top of the kettle
   (c) not more than halfway up the sides of the kettle
   (d) not more than 2/3 of the way up the sides of the kettle

8. Which of the following precautions should you take when using an acetylene torch to seal small cuts in a cable?

   (a) Do not use the torch underground.
   (b) Do not use the torch in a confined space.
   (c) Do not use the torch near the end of a pipe leading underground.
   (d) All of the above.

9. In charging a lead storage cell, reduce the charge if the temperature reaches a maximum of

   (a) 125 F
   (b) 110 F
   (c) 95 F
   (d) 80 F

10. How low a voltage may be considered as a possible source of danger?

11. No work should be done on energized conductors and equipment except when

    (a) the lines and equipment are deenergized and grounded
    (b) adjacent energized lines and equipment are adequately protected by insulation and protective rubber equipment
    (c) work can be performed between 2 sets of grounds
    (d) hot-line tools are used

12. What specific precaution should you take before opening a ground connection at a ground pipe or a ground bus bar?

13. What precaution should you take before grounding a supposedly dead circuit?

14. Which of the following is the recommended precaution to take in moving energized cables of voltages less than 12 kv?

    (a) Never move them.
    (b) Move them a maximum distance of 3 ft.
    (c) Move them a maximum distance of 18 in.
    (d) Move them a maximum distance of 1 ft.

15. You should wear approved and tested gloves under which of the following conditions?

    (a) While cutting a supposedly dead cable
    (b) While working near a man in reach of an energized circuit
    (c) While tending reels where wires are being strung close to energized conductors
    (d) All of the above

16. What is the recommended maximum amount of flammable liquid that may be stored inside a building?

17. How can you free a fellow workman from contact with a live conductor, if it is not possible to turn off the voltage?

18. When a victim of electrical shock begins to respond to artificial respiration, why should you not let him stand up, or even sit?

APPENDIX I
ANSWERS TO QUIZZES
Chapter 2
ELECTRICAL THEORY

1. Electrons may be put into motion by the application of friction, heat, light, pressure, or magnetism, or by chemical action.

2. (d).

3. (c).

4. (b).

5. The basic circuit must have (1) an energizing source with negative and positive terminals, (2) a conductor, and (3) a device for cutting the source in or out.

6. Normally, the 3 sources of resistance in a circuit are: (1) resistance in the energizing source itself, (2) resistance in the conductor, and (3) resistance in the load.

7. (b).

8. (a).

9. In a series circuit, there is only one path along which the movement of electrons takes place; in a parallel circuit, there are 2 or more paths along which electrons may move.

10. Kirchhoff's law of voltages is that the algebraic sum of the voltages around a circuit is zero.

11. In a parallel circuit, each load is connected directly with the voltage source.

12. (a).

13. (a).

14. (d).

15. (d).

16. (a).

17. (c).

18. (b).

19. Series motors are best for use where heavy loads are coupled to the motor; shunt and compound motors are best where the speed of the load must be held practically constant.

20. (c).

21. Speed control is obtained on a shunt motor by use of a resistor element connected in series with the field.

22. In a d-c motor run as a generator, the direction of the current at the brushes is from the motor to the external circuit.

23. Reversing the leads on a series motor will reverse the current flow through the armature, and change the direction of rotation of the motor.

24. (c).

25. There is a low limit on the voltage for an a-c motor designed with slip rings and brushes, because of the danger of arcing between ring and ring, ring and brush, brush and brush, or brush and frame.

26. On most a-c synchronous motors, the armature windings are placed in the stator in order to protect them from the centrifugal force of the rotor.

27. Single-phase windings are connected in series, with one set of coils terminating in two free ends.

28. Three-phase windings may be either Y-connected or delta-connected, in series or in parallel.

29. In a 3-phase motor with Y-connected armature, line voltage is 1.73 times phase voltage; line current and phase current are of the same value.

30. Phasing is the difference in timing of the induced voltages in two or more windings on a stator; it results from the fact that the flux field of the rotor does not cut each winding at the same time.

31. (d).

32. The 3 factors necessary for automatic starting of an induction motor are: an induced voltage in the rotor windings, a short

circuit in the rotor windings, and a torque produced by a rotating magnetic field.

33. (c).

34. The type of motor that will work on either d-c or a-c current is the series-Universal motor.

35. Three types of secondary protective devices for use in a circuit are fuses, switches, and circuit breakers.

36. (c).

37. In place of a rheostat, a multi-tapped resistor is sometimes used to vary resistance in a circuit.

38. In the case of d-c generators, voltage control refers to the use of a rheostat or other device to bring about an intentional change in terminal voltage; voltage regulation refers to the use of automatic controls, called voltage regulators, for the maintenance of voltage throughout a system, where the characteristics of the generator would cause changes in terminal voltage.

Chapter 3

DIAGRAMS AND SCHEMATICS

1. (d).

2. The type of drawing that shows all objects drawn to scale in all respects is an isometric drawing.

3. (c).

4. Drawings prepared by BuDocks to facilitate the erection and wiring of structures at advanced bases are available in Advanced Base Drawings, NavDocks P-140.

5. The electrical symbols required for use by all departments of the armed services are listed in MIL-STD-15A, Electrical and Electronics Symbols.

6. (b).

7. (a).

8. The 3 distinctive features of wiring diagrams are: (1) indication of terminal connections, (2) showing of items or parts in approximately true locations, and (3) representation of items by shape or appearance, instead of by electrical symbols.

9. The block diagram is designed to give an overall picture of the functioning of a piece of electrical equipment.

10. (b).

11. An open circuit in a wiring system is indicated when current is not reaching the point where it is needed, a short or a ground is indicated by a blown fuse.

12. When you must check a junction box for a short, be sure to remove the fuse before you disconnect or connect any wires.

13. The 3 devices, as listed in the text, for checking circuits not yet connected to a power distribution system are: bell and battery, ohmmeter, and megger.

Chapter 4

WIRING

1. (a).

2. (d).

3. The insulation used on a free end of any conductor must be equivalent to that on the conductor.

4. When the service entrance switch is in the ON position, it closes the circuit between the outside distribution source and the inside wiring.

5. A panel distribution board should be located as near as possible to the center of the electrical load it is to service.

6. The two major purposes served by an outlet box are: (1) to connect the elements of the electrical system, and (2) to provide a convenient space for mounting devices.

7. (c).

8. (b).

9. The type of conduit that comes threaded at both ends of each 10-ft length is rigid conduit.

10. A length of conduit that has been cut with a hand saw or a pipe cutter should be reamed to remove the ragged edge left inside.

11. (d).

12. The opening in an L fitting simplifies the task of fishing wires through a 90-degree bend in a conduit.

13. (b).

14. (c).

15. The chief advantage of using stranded rather than solid conductors is that the stranded ones have greater flexibility.

16. Size of wire is indicated (1) by mils, or (2) by an AWG standard number.

17. Insulation has its voltage rating, so that what is satisfactory on a 110-V line might be dangerous on a 220-V line.

18. In an interior wiring system, insulation is especially important, because the wires must be so close to each other that poor insulation would result in shorts or grounds.

19. (c).

20. It is permissible to use Romex or BX for the interior wiring system of such temporary prefabricated structures as quonset huts.

21. Where flexible cord is used in an installation, make sure (1) that it is used only as a continuous length, (2) that it is never used in a concealed installation, (3) that it is never used where it must be attached to the building surface, and (4) that it is never carried through any type of opening in wall, ceiling, or floor.

22. In general, the number of wires to be installed in each conduit depends upon the electrical plan from which you are working.

23. The use of knife switches with an amp rating 25 percent higher than the expected current load provides a margin for contact wear and for possible slight misalignment.

24. The reason for installing fuses in an electrical wiring system is to protect against dangerous overload.

25. The 3 classes of device that will open circuit breakers are: overload, low voltage, and reverse current.

26. A reverse current circuit breaker is the type installed on paralleled generators.

27. (a).

28. The maximum number of watts that can be permitted on a circuit is determined by multiplying the voltage of the circuit (in volts) by the current (in amp) flowing through it.

29. An underplaster extension is allowable when there is no open space in floor or partition through which wires can be fished, and when the installation is on the same floor, and requires small-sized conduit or tubing.

Chapter 5

METERS AND CONTROLS

1. A current-measuring instrument must be connected in series with the line and with the load.

2. The 2 primary factors listed in the text as placing limitations on the current rating of a multirange ammeter are: size of the

instrument, and requirements of the range-switching mechanism.

3. If you must connect an ammeter into a circuit carrying a current of unknown value, select the highest available range. If this proves too high, try lower ranges successively, till you get the correct reading.

4. Voltage-measuring instruments must be connected in parallel with the circuit to be tested.

5. (b).

6. When fixed resistors are connected inside a voltmeter, the dial of the instrument is calibrated to show a scale for each resistor.

7. (d).

8. The meter instrument used to indicate how much power is being wasted in a circuit is the power factor meter.

9. The practical purpose of using a rectifier in a meter device is to change a-c to d-c.

10. (d).

11. (c).

12. (a).

13. (c).

14. (b)

15. The range of a frequency meter is usually restricted to a few cycles on either side of normal frequency for the equipment.

16. Automatic voltage regulators are necessary on a-c generators to maintain proper voltage during load changes.

17. (a).

18. If you connect a d-c meter to an a-c source, the current will probably burn out the meter coil.

19. Avoid rubbing the glass-covered dial of any indicating instrument just before you take a reading, because the friction can produce a small electrostatic charge that may attract the pointer.

20. You can check the accuracy of a frequency meter by computing true frequency from the number of poles and the speed of the generator that is supplying power.

Chapter 6

POWER DISTRIBUTION SYSTEM

1. (d).

2. The distribution system in which each feeder is made up of 3 wires is known as a 3-wire delta system.

3. If a generator is to produce high voltages, the field poles must be powerful, the armature winding must be made up of a great number of turns, and the coils must be rotated at high speeds.

4. (c).

5. The standard formula for determining the frequency of an a-c motor is:

   Frequency =

   $$\frac{\text{No. of field poles x generator rpm}}{120}$$

6. Types of d-c generators are distinguished according to the type of windings on the field poles.

7. (b).

8. When power station generators are being installed, give careful consideration to the 3 factors: vibration, ventilation, and grounding.

9. The output voltage from a generator is delivered at the bus bars; it is controlled at the switchboard.

10. In a 3-phase type of generator, the stator coils are set 120 electrical degrees apart, on the stator core.

11. (c).

12. (a).

13. Phase sequence can be easily determined if the ends of the stator coils are identified where they are brought out to the terminals.

14. (d).

15. The elapsed time meter indicates the number of consecutive hours that the unit has been in operation, and is a guide to lubrication and maintenance needs.

16. With the voltage regulator switch in the OFF position, it is possible to adjust generator output voltage by means of the field rheostat.

17. The function of an a-c wattmeter is to indicate power output in kilowatts.

18. (a).

19. Current through the primary of a current transformer is determined by the load on the system.

20. The load on the meter or other measuring device determines current through a voltage transformer.

21. It is important to have a grounding plan for any switchgear unit, because there are so many noncurrent-carrying metal parts that permit development of an electrostatic field.

22. Underground cables should be used at an advanced base, in preference to overhead systems, to prevent hazardous conditions, or to ensure a continuous service that an overhead system could not provide.

23. The purpose of the 45-degree roof on line-carrying poles is to drain off moisture which might otherwise rot the pole.

24. (b).

25. In an overhead system, the gains on adjacent poles face in opposite directions, and the gain on a dead-end pole always faces away from the line.

26. Double crossarms are used on a pole at terminals, corners, angles, and other points of added strain.

27. (b).

28. If the wires in an overhead system are stretched too tight, they may break under the strain of ice or high winds.

29. The 3 factors that determine the amount of sag are: length of span, temperature at the time the wires are strung, and expected weather conditions.

30. Moisture in an underground cable system is very likely to penetrate the lead sheath, and cause a voltage breakdown between conductors.

31. The function of a distribution transformer is to raise, or to lower, voltage between distribution and consumption points.

32. The advantage of the 2 secondary windings on a single-phase distribution transformer is that you get the same result as if you had 2 transformers connected to the same primary winding.

33. (c).

34. Power output of the secondary coil of a transformer is practically equal to power input of the primary coil.

35. The power factor of a transformer is computed in the same way as the power factor of any electrical circuit.

Chapter 7

OPERATION OF GENERATING EQUIPMENT

1. The 2 major steps in starting an A-C generator are: bringing the prime mover up to rated speed, and operating the switchboard controls to bring power onto the bus.

2. (b).

3. (c).

4. (d).

5. A circuit breaker is not usually installed as overload protection on generators operating in parallel because opening of the circuit breaker might make it necessary to resynchronize the units.

6. The formula for computing effective power of an A-C generator is:

$$P.\ F. = \frac{\text{watts}}{\text{volts x amperes}}$$

7. The power factor of an A-C load indicates what portion of total power is actually being made available for the load.

8. Before 2 generators can safely be paralleled, the incoming generator voltage must be approximately equal to the bus voltage, the incoming generator voltage must have the same frequency as bus voltage, and the incoming generator voltage must be in phase with bus voltage.

9. (c).

10. After you have paralleled two generators, watch the A-C ammeters of both units until they show the same reading.

11. (d).

12. (d).

13. The man standing a generator watch must: (1) operate the station equipment, (2) maintain the station equipment, and (3) maintain the operating log.

14. (a).

15. In inspecting switchboard meters, look for cracked or broken glass, damage to cases, and accuracy of the pointer.

16. (b).

17. The common cause of failure in bushings on high voltage lines is the shrinkage of the inelastic compound, and the resulting cracks.

18. (b).

19. (a).

Chapter 8

COMMUNICATIONS SYSTEMS

1. The normal talking range of a field wire installation can be extended by the use of loading coils or repeaters.

2. (a).

3. The receiver in a telephone subset reconverts into sound waves of corresponding waveform and frequency the electrical waves produced at a transmitter.

4. (c).

5. In a common battery system, the stations must be connected in parallel, as far as direct current is concerned, and the battery must be connected across the line.

6. An antisidetone circuit between two telephone sets prevents the passage of voice currents from the transmitter of a set to the receiver of the same set.

7. (b).

8. Field wires in telephone line construction must be kept to minimum length because of high transmission losses.

9. (d).

10. (c).

11. The 2 methods used for fastening a cable to a suspension strand are (1) cable rings, and (2) lashing.

12. If a reel runs out when you are laying buried cable for a communications system, you will have to bring the end of the wire to the surface of the ground, or into a splicing chamber, for splicing.

13. Connections between subsets and main run are made in a pole-mounted terminal box by attaching the drop wires from each subset, and the designated pair of wires from the cable stub, to a single set of binding posts.

14. When several telephone stations are connected by means of a switchboard, interconnections are made at the switchboard by means of the line jacks.

15. (c).

16. A distribution frame provides for an orderly arrangement of incoming lines, and for the identification of the lines entering the central office.

17. (d).

18. (b).

19. (a).

20. The functions of cord circuits on a central office switchboard are to provide electrical paths between stations, and to prevent the branch that contains the common battery from shorting out the receiver of the listening station.

21. In making the connection between two lines, the switchboard operator moves the switch key (1) forward to the talking position, (2) backward to the ringing position, and then (3) into neutral position.

22. (d).

23. Fuses protect telephone lines by limiting the current that can reach the output terminals, to which the subset wiring is connected; lightning arresters prevent high potential from reaching the output terminals by bypassing it to ground.

24. When you are routing inside wiring from protectors to subset locations, make the run parallel with, or at right angles to, the building walls.

25. (c).

26. Two low-voltage sources for energizing a bell circuit are (1) dry cells, and (2) a bell transformer connected to a lighting circuit.

27. (b).

28. In a dial telephone system, connector banks instead of switchboard jacks serve as the terminal points for the wires from the subsets.

29. In a dial system, the spinning of the dial operates a cam which opens the impulse circuit; and the impulses cause the electromagnets to move the shafts a corresponding number of steps.

30. The third position of the switches on the selector switch panel of an intercom system is for operating the annunciator on a remote MASTER STATION unit.

31. (c).

32. (c).

33. (b).

Chapter 9

TELEPHONE CABLE SPLICING

1. (c)

2. Composite cable is cable that includes two or more sizes of conductors.

3. The 3 commonly used types of telephone cable splicing are: straight, bridge, and butt splicing.

4. The sheaths of cables to be spliced should be cleaned for a distance of several inches so that these areas will be ready for the subsequent tinning.

5. The edges where the sheath has been broken off must be smoothed in order to protect the cable core from damage during the splicing operation.

6. The lead sleeve covers the cable opening where splicing has been done.

7. The 3 major factors that determine the size of a lead sleeve are: size of cable, size of conductors, and type of splice to be made.

8. The major purpose of boiling out insulation in an area where splicing is to be done is to remove moisture.

9. (c).

10. A desiccant removes the moisture from cable insulation by abosrbing it.

11. (d).

12. Unless you stagger the individual joints in each pair of wires, the lead sleeve may not be adequate to cover the splice opening.

13. (c).

14. (a).

15. The catch cloth is moved back and forth during a tinning operation, to ensure that the bottom of the joint is tinned; if the cloth were wrapped around the joint, it would tear on the sharp points formed as the wiping metal chills.

16. To ensure a good wipe, heat the sheath and sleeve to the same temperature as that of the wiping solder.

17. (b).

18. The disadvantage of using a cable saw to split a lead sleeve is that you may damage the inside wall of the sleeve.

19. (d).

20. Cable heads are short lengths of lead-covered textile-insulated cables; they serve as connectors between incoming paper-insulated cable and distributing frames, terminal strips, or other interior terminal points.

21. Beeswax is used for boiling out silk and cotton insulated cable, because paraffin discolors a textile insulation.

22. In making minor repairs for cuts or breaks in a cable, use the carbon electrode welding method if the breaks have penetrated the sheath, and allowed moisture to reach the conductor insulation; use an acetylene torch if the breaks do not extend through the sheath.

23. (d).

24. The acetylene torch is safer for work on aerial cables than for work in manholes, because acetylene is highly flammable, and explosive in confined spaces.

Chapter 10

SHOP WORK

1. Unless the components of electrical equipment are carefully handled, insulation may be damaged, and the equipment may develop shorts or grounds.

2. Most a-c generators have 6 stator leads; that is, one pair to each phase.

3. One single factor that will go a long way towards keeping an advanced base generator in good working order is the maintaining of a regular schedule of inspection, cleaning, and lubricating.

4. (b).

5. (d).

6. In removing an armature from a machine, wear canvas gloves to prevent the shaft keyways from cutting your hands.

7. (d).

8. (c).

9. (a).

10. (c).

11. (b).

12. To compute the number of coils in a group for a 2-pole 3-phase machine, count the total number of slots in the stator, and divide this figure by 6 (product of 2 x 3).

13. The direction of current flow should reverse in successive pole-phase groups, so that a north pole will always alternate with a south pole.

14. After armature, stator, or field coils have been wound, taped, dipped, and baked, they must be tested for opens, shorts, grounds, and polarity.

15. (a).

16. Never bake an armature immediately after dipping, since the application of heat will form a skin on the surface of the varnish, and seal in the moisture.

17. (a).

18. Sealed-type commutators will probably require greasing after every 5,000 hours of operation.

19. Before starting any repair or overhaul of a motor, you should (1) analyze the probable trouble; (2) check the data on the nameplate; and (3) take the necessary data during the process of disassembly.

20. You can make a thorough test for a ground on a 3-phase motor by connecting one lead of a test lamp to the motor frame, and the second lead to each motor lead in turn.

21. If the coils of a motor armature touch the core at the slots, the result will be grounding of the armature.

22. If a clamp-on ammeter attached to a 3-phase motor running without a load shows a current reading higher than the current value on the motor nameplate, a short is usually indicated.

23. You can make an approximate check on brush spacing by counting the number of commutator bars between brushes.

Chapter 11

SAFETY

1. Every man should be ready to make a prompt report of unusual conditions in a generating station or cable system, because these conditions may result in disruption of service, or danger to personnel or equipment.

2. When you leave a working space for any considerable time, store tools and materials in an appropriate place.

3. When a pole is being raised, stand back a distance equal to the length of the pole.

4. Before you go aloft on a pole, it will be advisable for you to take the following precautions: (1) make sure that the pole can support your weight; (2) inspect your body belt; (3) inspect your safety strap; (4) check your climbers.

5. (c).

6. (d).

7. (a).

8. (d).

9. (a)

10. A voltage as low as 35 volts may be considered as a possible source of danger.

11. (b).

12. Before opening a ground connection at a ground pipe or a ground bus bar, you should first check to see that it has been disconnected from the equipment that it is intended to ground.

13. Before you ground a supposedly dead circuit, use a switch stick to test the circuit for static discharge.

14. (c).

15. (d).

16. It is recommended that you never store more than 1 gal of flammable liquid inside a building.

17. To free a fellow workman from contact with a live conductor, when it is not possible to turn off the voltage, use rubber gloves or a similar nonconductor.

18. When a victim of electrical shock begins to respond to artificial respiration, do not allow him to sit or stand, as that may put a severe strain on his heart.

APPENDIX II

USEFUL INFORMATION FOR THE CE RATING

I. Conversion tables:

Formulas for converting temperatures from Fahrenheit to Centigrade, and vice versa, are:

5/9 (F minus 32) equals C

9/5 C plus 32 equals F

Electric power and energy units:

1 amp equals 1,000 milliamp; 1,000,000 microamp

1 milliampere equals 1/1,000 amp

1 microampere equals 1/1,000,000 amp

1 volt equals 1,000 millivolts; 1,000,000 microvolts

1 millivolt equals 1/1,000 volt

1 microvolt equals 1/1,000,000 volt

1 kilovolt equals 1,000 volts

1 ohm equals 1,000,000 microhms

1 microhm equals 1/1,000,000 ohm

1 megohm equals 1,000,000 ohms

1 watt equals 1/1,000 kilowatt

746 watts equal 1 horsepower (hp)

1 kilowatt equals 1,000 watts

1 kilowatt equals 1 1/3 hp, or 1.34 hp

kva represents the product of kilovolts and amperes

II. Formula for finding the rpm of an a-c generator when the number of poles and the frequency are known:

$$\text{rpm} = \frac{\text{frequency times 120}}{\text{number of poles}}$$

The frequency of an a-c generator is found by multiplying the number of armature revolutions made each second by half the number of poles. Thus, we have a formula for frequency:

$$\text{frequency} = \text{rps times poles}/2$$

From this we derive the formula for revolutions per second:

$$\text{rps} = \text{frequency} \div \text{poles}/2\text{, or, rps} = \frac{\text{freq times 2}}{\text{poles}}$$

However, the usual method of expressing generator speed is in terms of revolutions per minute: and rpm is 60 times rps. Therefore, the formula is:

$$\text{rpm} = \frac{\text{frequency times 120}}{\text{number of poles}}$$

III. Power factor is the ratio between (1) actual power and (2) apparent power as represented by the product of watts and amperes. When actual and apparent power is an identical value, power factor is represented by 1.0, or unity. In all other cases, it is expressed as a decimal.

The formulas for finding power factor on a-c equipment are:

1. For single phase, use

$$\text{P. F.} = \frac{\text{watts}}{\text{amperes times volts}}$$

$$\text{or, kilowatts} \div \frac{\text{amperes times volts}}{1,000}$$

2. For three phase, use

$$\text{P. F.} = \frac{\text{watts}}{\text{amperes times volts times 1.73}}$$

$$\text{or, kilowatts} \div \frac{\text{amperes times volts times 1.73}}{1,000}$$

IV. Formulas for computing the current that a-c motors will draw at full load:

1. For single phase, use

$$\text{amp} = \frac{\text{hp times 746}}{\text{volts times P. F. times Eff}}$$

where hp represents the horsepower of the motor, as indicated on the motor nameplate

Eff represents the motor efficiency at full load, as indicated on the motor nameplate

P. F. is the power factor decimal

2. For three phase, use

$$\text{amp} = \frac{\text{hp times 746}}{\text{volts times 1.73 times P. F. times Eff}}$$

These formulas can be equally well employed for finding the horsepower of a motor, if this data is not available. However, do not use the formulas to compute efficiency, voltage, or power factor.

In finding horsepower, you can put all the other values into the formula, and compute for the one unknown value, or you can rearrange the formulas as follows:

$$\text{Hp} = \frac{\text{amp times volts times P. F. times Eff}}{746}$$

$$\text{or } \frac{\text{amp times volts times 1.73 times P. F. times Eff}}{746}$$

according to whether the motor is single phase or three phase.

For computing the current or the horsepower of a d-c motor, use the formula given for single phase, but omit the power factor.

To find the value of an alternating current when voltage, power (in watts) and power factor are known, use the formulas:

$$\text{amp} = \frac{\text{watts}}{\text{volts times P. F.}}\text{, or}$$

$$\text{amp} = \frac{\text{watts}}{\text{volts times 1.73 times P. F.}}\text{,}$$

according to whether the equipment is single phase or three phase.

V. Table showing full-load currents of motors:

[The following data are approximate full-load currents for motors of various types, frequencies, and speeds. They have been compiled from average values for representative motors of their respective classes. Variations of 10 percent above or below the values given may be expected.]

Hp. of motor	Amperes—Full-load current																								
	Direct-current motors			Alternating-current motors																					
				Single-phase motors		Squirrel-cage induction motors										Slip-ring induction motors									
						Two-phase					Three-phase					Two-phase					Three-phase				
	115-volt	230-volt	550-volt	110-volt	220-volt	110-volt	220-volt	440-volt	550-volt	2,200-volt	110-volt	220-volt	440-volt	550-volt	2,200-volt	110-volt	220-volt	440-volt	550-volt	2,200-volt	110-volt	220-volt	440-volt	550-volt	2,200-volt
¼				4.8	2.4																				
½	4.5	2.3		7	3.5	4.3	2.2	1.1	0.9		5.0	2.5	1.3	1.0											
¾	6.5	3.3	1.4	9.4	4.7	4.7	2.4	1.2	1.0		5.4	2.8	1.4	1.1		6.2	3.1	1.6	1.3		7.2	3.6	1.8	1.5	
1	8.4	4.2	1.7	11	5.5	5.7	2.9	1.4	1.2		6.6	3.3	1.7	1.3		6.7	3.4	1.7	1.4		7.8	3.9	2.0	1.6	
1½	12.5	6.3	2.6	15.2	7.6	7.7	4.0	2	1.6		9.4	4.7	2.4	2.0		11.7	5.9	3.0	2.3						
2	16.1	8.3	3.4	20	10	10.4	5	3	2.0		12.0	6	3.0	2.4		12.5	6.3	3.1	2.5		14.4	7.2	3.6	2.9	
3	23	12.3	5.0	28	14		8	4	3.0			9	4.5	4.0			8.7	4.3	3.5		20.2	10	5.0	4	
5	40	19.8	8.2	46	23		13	7	6			15	7.5	6.0			13.0	6.5	5.2			15	7.5	6	
7½	58	28.7	12	68	34		19	9	7			22	11	9.0			20.0	10.0	7.6			25	13	10	
10	75	38	16	86	43		24	12	10			27	14	11			24.3	12.1	10.0			28	14	11	
15	112	56	23				33	16	13			38	19	15			39	19.5	15.6			45	23	18	
20	140	74	30				45	23	19			52	26	21	5.7		49	24.7	19.8			56	28	22	
25	185	92	38				55	28	22	6		64	32	26	7		60	30.0	24.0	6.4		67	34	27	7.5
30	220	110	45				67	34	27	7		77	39	31	8		72	36.0	28.8	7.8		82	41	33	9
40	294	146	61				88	44	35	9		101	51	40	10		93	46.5	37.3	9.5		106	53	42	11
50	364	180	75				108	54	43	11		125	63	50	13		113	57	45	12.1		128	64	51	14
60	436	215	90				129	65	52	13		149	75	60	15		135	68	54	14.0		150	75	60	16
75	540	268	111				156	78	62	16		180	90	72	19		164	82	65	17.3		188	94	75	19
100		357	146				212	106	85	22		246	123	98	25		214	108	87	21.7		246	123	99	25
125		443	184				268	134	108	27		310	155	124	32		267	134	108	27		310	155	124	31
150			220				311	155	124	31		360	180	144	36		315	158	127	32		364	182	145	37
175																									
200			295				415	208	166	43		480	240	195	49		430	216	173	44		490	245	196	52

VI. Table showing connections for three-phase generators:

Required voltage	Connect lead lines (via circuit breaker) to --			Connect
220-volt[1] single-phase, 2-wire	T27 & T8	---------	T3 & T9	T5 to T6
440-volt[1] single-phase, 2-wire	T3	---------	T8	T2 to T9 T5 to T6
220/440-volt[1] single-phase, 3-wire	T3	T2 & T9 neutral	T8	T5 to T6
440-volt three-phase, 3-wire	T1	T2	T3	T4 to T7 T5 to T8 T6 to T9
127/220-volt three-phase, 3-wire	T1 & T7	T2 & T8	T3 & T9	T4, T5, T6 & T0 for neutral

[1] Tape individually T1, T4, T7, T0

VII. Pole Classifications:

Wood poles are usually classified according to length; that is, they are in 25, 30. 35, 40, 45, 50 foot lengths, and so on. Notice that the lengths vary in 5-ft steps. Poles for telephone lines should be 40 to 60 ft, but 30 to 40 ft is common for distribution systems.

Poles are also classified as to circumference, measured 2 ft from the top of the pole, and 6 ft from the butt end. Circumference at the top varies by 2-in. steps; that is, minimum top circumferences are 15, 17, 19, 21, 23, 25, and 27 inches.

Load resistance must meet the following requirements:

Class of pole	Minimum top circumference (in.)	Load force that pole must be able to withstand (lb)
1	27	4,500
2	25	3,700
3	23	3,000
4	21	2,400
5	19	1,900
6	17	1,500
7	15	1,200

In some tables, you will find data on "resisting moments," in ft-lb. Divide this figure by the LEVER ARM of the pole (overall length minus length below ground minus distance from pole top at which force is applied), and you will have the load force that the pole must be able to withstand.

VIII. Vertical Separation Between Cross-arms:

Vertical spacing between cross-arms depends upon the nature of the circuits, and the voltage carried. The National Electric Code suggests the following minimum distances for vertical separations:

Service Required of Conductors	Voltages			
	0-750	750-8,700	8700-15,000[1]	15,000-50,000[2]
Supply	2	2	4	6
Communications (general)	4	4	6	6

[1] A minimum of 2 ft is allowable, if the lines are not live when worked on; or if live, are shielded from adjacent circuits. Also, if linemen use long-handled tools, and are not required to go between wires, a 2-ft vertical separation is considered safe.

[2] Where supply lines render service to a single utility, a 4-ft clearance is sufficient.

IX. Recommended spacing for conductors, for various voltages, where there is only a moderate space between poles:[1]

Line Voltage	Distance between line conductors (in.)
2,300	12 to 18
6,600	18 to 24
13,200	18 to 24
22,000	30 to 36
33,000	36 to 48
44,000	48 to 60
66,000	72
88,000	96
110,000	120
220,000	192
330,000	264

[1] The greater the span between poles, the greater the spacing, to prevent conductors touching during high winds. Minimum spacing permissible for a span as long as 300 ft is 48 in.; for a 400-ft span, 54 in.; for a 500-ft span, 60 in.; for a 600-ft span, 72 in.

X. Recommended sizes for cotton sleeves used in cable splicing operations:

Gage of Conductor	Type of Splice	Sleeve Diameter [1] (in.)	Type of Wall [2]
24	Straight, butt	1/8	Single
24	Bridge	1/8	Single
22	Straight, butt	5/32	Single
22	Bridge	5/32	Single
19	Straight, butt	5/32	Double
19	Bridge	1/4	Double
16	Straight, butt	1/4	Double
16	Bridge	1/4	Double

[1] Length of these sleeves, 3-1/4 inches.

[2] Use double wall sleeves on all soldered conductors.

XI. Color codes for textile-insulated cable:

Color-coded cable forms are frequently used for terminating lead-covered exchange cables with paper wrap or pulp insulation at distribution frames. The conductors of these cable forms are 22-gage annealed copper; they are textile-insulated, and colored so that each pair may be readily distinguished from all other pairs in the cable. In one type the conductors are tinned: in another type, they are tinned and enameled.

Cable for forms is made in various sizes from 6 to 202 pairs. Use tinned conductor cable in small buildings, and at central offices where less than 101 pairs are required. Use enameled conductor cable where a higher degree of insulation resistance is required.

The color code for these cable forms is as follows:

Pair No.	Tip Wire	Ring Wire
1	White	Blue
2	White	Orange
3	White	Green
4	White	Brown
5	White	Slate
6	White	Blue-white
7	White	Blue-orange

The color code for these cable forms is as follows: (Cont'd)

Pair No.	Tip Wire	Ring Wire
8	White	Blue-green
9	White	Blue-brown
10	White	Blue-slate
11	White	Orange-white
12	White	Orange-green
13	White	Orange-brown
14	White	Orange-slate
15	White	Green-white
16	White	Green-brown
17	White	Green-slate
18	White	Brown-white
19	White	Brown-slate
20	White	Slate-white
21- 40	Red	First 20 colors repeated
41- 60	Black	First 20 colors repeated
61- 80	Red-white	First 20 colors repeated
81-100	Black-white	First 20 colors repeated
101-120	Red-black	First 20 colors repeated
121-140	Black-orange	First 20 colors repeated
141-160	Black-green	First 20 colors repeated
161-180	Black-brown	First 20 colors repeated
181-200	Black-slate	First 20 colors repeated
201 [1]	White	Red
202 [2]	White	Black

[1] In cables from 6 to 101 pairs, the highest numbered pair has the same colors of insulation as that shown for the pair designated as 201.

[2] In the 152 pair cable, pairs 151 and 152 have colors of insulation corresponding to pairs 201 and 202, respectively.

APPENDIX III

QUALIFICATIONS FOR ADVANCEMENT IN RATING

CONSTRUCTION ELECTRICIAN (CE)

Quals Current Through Change 14

General Rating (applicable to PO1 and CPO only)

Scope

Construction electricians plan, supervise, and perform tasks required to install, operate, service, and overhaul electric generating and distribution systems and wire communication systems: Control activities of individuals and crews who string, install, and repair interior, overhead, and underground wires and cables and attach and service units such as transformers, switchboards, motors, and controllers; schedule and evaluate installation and operational routines; and train personnel in installation and repair procedures and techniques.

Service Ratings (applicable to PO3 and PO2 only)

Scopes

CONSTRUCTION ELECTRICIAN W (Wiring) . . . . CEW
Install, service, perform preventive maintenance on, and repair interior wiring systems and secondary electric distribution circuits. Install motors, generators, controllers, switchboards, distribution panels, and appliances.

CONSTRUCTION ELECTRICIAN P (Power) . . . . CEP
Install, operate, service, perform preventive maintenance on, make repairs to, and overhaul electric generating and distribution systems, overhead and underground.

CONSTRUCTION ELECTRICIAN T (Telephone) . . . . CET
Install, operate, service, perform preventive maintenance on, make repairs to, and overhaul wire communication systems, overhead and underground.

CONSTRUCTION ELECTRICIAN S (Shop) . . . . CES
Operate, service, perform preventive maintenance on, repair, and overhaul electric generating equipment, switchboards, distribution panels, motors, generators, and controllers. Repair and overhaul electric appliances.

PATH OF ADVANCEMENT TO WARRANT OFFICER AND LIMITED DUTY OFFICER
Construction Electricians advance to Warrant, Civil Engineer Corps and/or Limited Duty Officer, Civil Engineer Corps.

Navy Enlisted Classification Codes

For specific Navy enlisted classifications included within this rating, see Manual of Navy Enlisted Classifications, NavPers 15105-A, codes CE-5600 to CE-5699.

Qualifications for Advancement in Rating

1. Qualifications for advancement to a higher rate include the qualifications of the lower rates or rates in addition to those stated for the higher rate.
2. Practical factors will be completed before recommendation for participation in the advancement examination. (Bureau of Naval Personnel Manual, NavPers 15791, Articles B 2327 and C 7201.)
3. Knowledge factors and knowledge aspects of practical factors will form the basis for questions in the written advancement examinations.

Qualifications for Advancement in Rating	Applicable Rates				
	CEW	CEP	CET	CES	CE
A. WIRING					
1.0 PRACTICAL FACTORS					
1. Make mechanical and soldered electrical connections and splice wire	3	3	3	3	--
2. Make minor repairs to electrical fixtures and wiring	3	3	3	3	--
3. Climb poles	3	3	3	3	--
4. Make minor on-site repairs to electric appliances	3	--	--	--	--
5. Install electric wiring, fixtures, and conduits	3	--	--	--	--
6. Correct minor faults in wiring systems	3	--	--	--	--
7. Lay out and install secondary interior electric circuits including service entrance controls	2	--	--	--	--
8. Analyze faults and make on-site repairs to electric appliances and circuits	2	--	--	--	--
2.0 KNOWLEDGE FACTORS					
1. Common properties of electrical circuits (resistance, inductance, capacitance) and units of electricity (volts, amperes, ohms) and use of Ohm's law	3	3	3	3	--
2. Types of information found in the national electric code	2	2	--	2	--
B. ELECTRICAL GENERATORS AND MOTORS					
1.0 PRACTICAL FACTORS					
1. Operate and service advanced-base-type generating equipment	--	3	--	--	--
2. Perform preventive maintenance on electric motors and advanced-base-type generating equipment	--	3	--	--	--
3. Synchronize alternators; stand generator switchboard watches and keep operational log	--	3	---	--	--
4. Make major repairs to and overhaul generating and control equipment of advanced base type, excluding prime movers	--	2	--	--	--
5. Rewind, insulate, and bake armatures and field coils	--	--	--	3	--
6. Analyze and correct faults in electrical equipment and circuits common to maintenance shops	--	--	--	2	--
7. Make major repairs to electric motors, portable generators, and appliances	--	--	--	2	--
8. Locate, analyze, and repair circuit faults common to:					
a. Electric generating and distribution systems	--	2	--	--	--
b. Electric appliances and equipment	--	--	--	2	--
c. Wire communication systems	--	--	2	--	--
9. Install advanced-base-type generators, switchboards, and distribution panels	--	2	--	--	--
2.0 KNOWLEDGE FACTORS					
1. Principles of electrical theory as applied to:					
a. a.c. and d.c. motors	--	--	--	2	--
b. Generators, transformers, and distribution systems	--	2	--	--	--
c. Wire communication systems	--	--	2	--	--
2. Types, construction, characteristics, and uses of a.c. and d.c. motors and generators	--	2	--	2	--

Qualifications for Advancement in Rating	Applicable Rates				
	CEW	CEP	CET	CES	CE
B. ELECTRICAL GENERATORS AND MOTORS - Continued					
3. Relationship of generator capacity to distribution system capacity; methods of improving power factor	--	2	--	--	--
C. ELECTRICAL POWER DISTRIBUTION SYSTEMS					
1.0 PRACTICAL FACTORS					
1. Work as crew member erecting pole line and accessories and installing underground cable for electric distribution systems	--	3	--	--	--
2. Make minor repairs to correct circuit faults in electric distribution systems and equipment	--	3	--	--	--
3. Analyze and correct faults in electric distribution systems	--	2	--	--	--
4. Install transformers	--	2	--	--	--
5. String overhead electric distribution lines; and install underground power cable	--	2	--	--	--
6. Install instrument transformers in power distribution circuits	--	2	--	--	--
7. Splice cable and make connections in electric distribution systems	--	2	--	--	--
8. Install, troubleshoot, and service all types of automatic controllers	--	--	--	--	1
2.0 KNOWLEDGE FACTORS					
1. Uses and types of:					
a. Secondary electric circuit protective devices and switches	3	3	3	3	--
b. Primary electric circuit protective devices and switches; controllers, relays, and solenoids	2	2	2	2	--
2. Methods and procedures for making major repairs and overhauling electric relays, solenoids, switches, circuit protective devices, and controllers	--	2	--	2	--
D. COMMUNICATION SYSTEMS					
1.0 PRACTICAL FACTORS					
1. Work as crew member erecting pole lines and accessories and installing underground telephone cable	--	--	3	--	--
2. Service and charge storage batteries used in wire communication systems	--	--	3	--	--
3. Make minor repairs to telephone wiring, subsets, and signal circuits	--	--	3	--	--
4. Install storage and dry-cell batteries used for wire communication systems	--	--	3	--	--
5. Operate and service manual telephone switchboards	--	--	3	--	--
6. Install interior telephone wiring, subsets, signal circuits, public address systems, and interoffice communication systems	--	--	2	--	--
7. Analyze, correct faults, and make major repairs to signal, telephone, public address, and interoffice communications systems	--	--	2	--	--
8. String overhead telephone lines and install underground telephone cable	--	--	2	--	--

Qualifications for Advancement in Rating	Applicable Rates				
	CEW	CEP	CET	CES	CE
D. COMMUNICATION SYSTEMS - Continued					
9. Splice overhead and underground cable; splice-in telephone cable terminals	--	--	2	--	--
10. Repair manual telephone switchboards	--	--	2	--	--
2.0 KNOWLEDGE FACTORS					
1. Types of manual and automatic telephone equipment used at advanced bases	--	--	3	--	--
E. TOOLS					
1.0 PRACTICAL FACTORS					
1. Select and use common electrical hand and power tools	3	3	3	3	--
2. Use voltmeter, ammeter, and ohmmeter in testing circuits and equipment.	3	3	3	3	--
3. Operate lathes to turn down commutators	--	--	--	3	--
2.0 KNOWLEDGE FACTORS					
1. Nomenclature and use of tools, materials, and equipment related to:					
a. Electric motors and generators	--	--	--	3	--
b. Electric distribution systems	3	3	--	--	--
c. Wire communication systems	--	--	3	--	--
2. Types and functions of meters used in electrical maintenance	2	2	2	2	--
3. Principles of operation of Wheatstone bridge, cable fault finders, and power circuit analyzers	--	--	--	--	1
F. DRAWINGS AND SKETCHES					
1.0 PRACTICAL FACTORS					
1. Read elementary wiring diagrams to perform tasks on:					
a. Interior wiring systems	3	--	--	--	--
b. Electric equipment and appliances	--	--	--	3	--
c. Electric distribution systems	--	3	--	--	--
d. Wire communication systems	--	--	3	--	--
2. Use electrical plans, diagrams, and schematics to install or repair:					
a. Interior wiring	2	--	--	--	--
b. Electric equipment and appliances	--	--	--	2	--
c. Electric distribution systems	--	2	--	--	--
d. Wire communication systems	--	--	2	--	--
3. Prepare sketches, employing conventional electrical symbols	--	--	--	--	1
2.0 KNOWLEDGE FACTORS					
1. Electrical symbols used on wiring diagrams and schematics	3	3	3	3	--

Qualifications for Advancement in Rating	Applicable Rates				
	CEW	CEP	CET	CES	CE
G. SAFETY					
1.0 PRACTICAL FACTORS					
1. Perform the following (under simulated conditions):					
a. Rescue of a person in contact with an energized circuit	3	3	3	3	--
b. Resuscitation of a person unconscious from electric shock	3	3	3	3	--
c. First-aid treatment for electric shock and burns and chemical burns	3	3	3	3	--
d. Pole-top resuscitation	3	3	3	3	--
2.0 KNOWLEDGE FACTORS					
1. Safety precautions to be observed when working with or in the vicinity of electric circuits and equipment	3	3	3	3	--
2. Safety precautions to be observed when:					
a. Handling molten lead compound and taping oil used in splicing	--	3	3	3	--
b. Climbing poles, buildings, and towers to string or work with wires and cables	3	3	3	3	--
c. Charging batteries	--	--	3	3	--
H. FOREMANSHIP					
1.0 PRACTICAL FACTORS					
1. Prepare inspection and progress reports, job orders, and material requisitions; stow and account for spare parts	--	--	--	--	1
2. Make equipment and material estimates from drawings, sketches, and specifications	--	--	--	--	1
3. Supervise watch in control room of an electric generating station	--	--	--	--	1
4. Supervise and train personnel engaged in the installation, operation, maintenance, and repair of electric generating and distribution systems, interior wiring and wire communication systems, and shop repair of equipment	--	--	--	--	1
5. Develop operational procedures and prepare reports for electric equipment and systems	--	--	--	--	C
6. Instruct personnel in practical application of a.c. and d.c. theory	--	--	--	--	C
7. Conduct training programs to qualify personnel for advancement in rating, including cross-training of service rating personnel for advancement to the general rating	--	--	--	--	C
8. Control site deployment of materials and equipment	--	--	--	--	C
9. Train individuals and drill crews in safe and expeditious execution of assigned tasks	--	--	--	--	C
10. Direct and coordinate composition and efforts of crews	--	--	--	--	C
11. Direct general job operations involving electric generating and distribution systems and wire communication systems	--	--	--	--	C
2.0 KNOWLEDGE FACTORS					
1. Principles and techniques of supervision and job control	--	--	--	--	1

Qualifications for Advancement in Rating	Applicable Rates				
	CEW	CEP	CET	CES	CE
I. DEFENSIVE TACTICS					
1.0 PRACTICAL FACTORS					
1. Maneuver fire teams into various formations by the use of hand and arm signals	--	--	--	--	C
2.0 KNOWLEDGE FACTORS					
1. Employment of fire teams in defensive positions	--	--	--	--	C
2. Instructions to be given perimeter guards	--	--	--	--	C

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